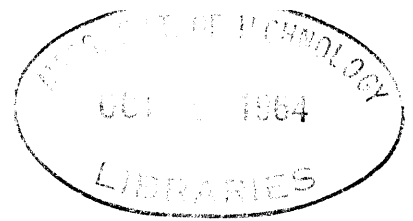




## BUILDINGS AS SYSTEMS



THE DEVELOPMENT OF A BUILDING UNIT  
WHICH IS STRUCTURALLY AND MECHANICALLY INTEGRATED  
AND WHICH ALLOWS MAXIMUM FLEXIBILITY  
IN INTERNAL REARRANGEMENT AND LATERAL GROWTH

by

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June, 1964

Signature of Author . (accepted in her absence) . . . . .

Selma Abigadol Hershendorfer

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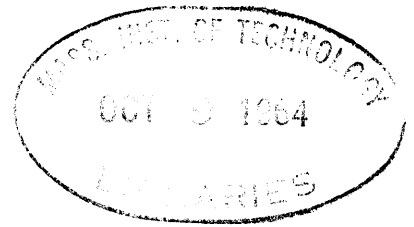
Eduardo Catalano

Thesis Supervisor

Accepted by . . . . .

Lawrence B. Anderson

Chairman,  
Department of Architecture



A RESEARCH AND DEVELOPMENT BUILDING  
FOR SCIENCE AND TECHNOLOGY  
SUITABLE FOR BOTH  
ACADEMIC AND NON-ACADEMIC USE

by

CHARLES BURTON HOOK

B. Arch., University of Illinois

(1963)

SUBMITTED IN PARTIAL FULFILLMENT  
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AN ACADEMIC / RESEARCH AND DEVELOPMENT  
BUILDING FOR SCIENCE AND TECHNOLOGY

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## PREFACE

The three individual theses are presented with a common introductory discussion on systems in general, the use of systems in architecture, and the overall goals and requirements for a building system. It is hoped that a better understanding of systems is attained as well as a more extensive background for the individual thesis material.

Part V of this thesis was written in collaboration with Virgil Raymond Smith in order to make a more complete presentation of the aim of the thesis.

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Individual Theses:

Hershdorfer, Selma A.

Hook, Charles B.

Hoover, G. Norman

## I. SYSTEMS

A system is a specific combination of elements which participate in the performance of a given function. They unite to form an integrated whole with a resultant pattern reflecting the regular interaction or interdependence among the parts. The original elements constitute the basic units whose repetition and varied combination determines the characteristics of the system.

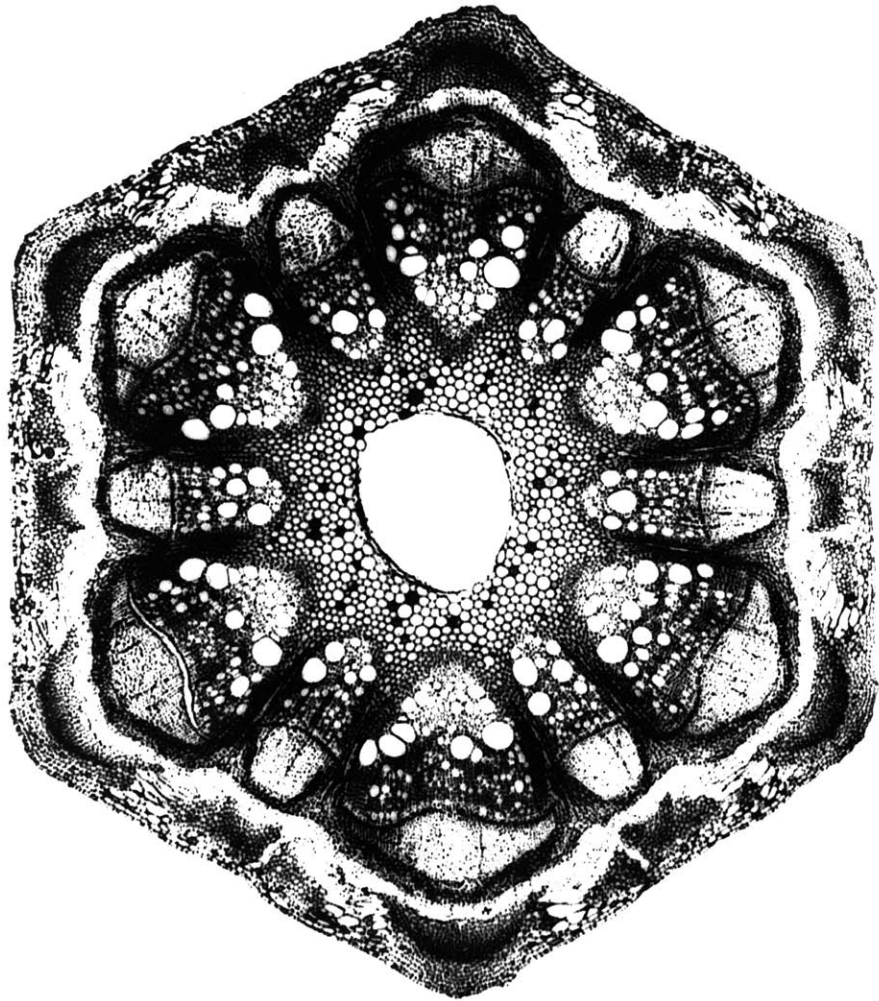
Natural systems develop spontaneously in response to physical laws. Almost all patterns found in nature reflect the effect of consistent forces and the specific responses of organisms to their environment. Environmental conditions also determine the various combinations of atoms or the formation of inorganic compounds. The physical and chemical characteristics of these compounds constitute regular and predictable systems.

Man has engaged in systematic research to discover means of controlling his environment. Cities and transportation networks have been built in response to environmental conditions. These constitute patterns--or systems--reflecting the nature of these conditions. Tools and machinery have been developed to control the physical environment while social systems have been formulated to control the relationships among men and, hopefully, to harmonize them.

## II. GRAPHIC EXAMPLES OF SYSTEMS IN GENERAL.

The following illustrations are presented with the hope that a better understanding of the meaning of systems might be attained.

Section of a twig



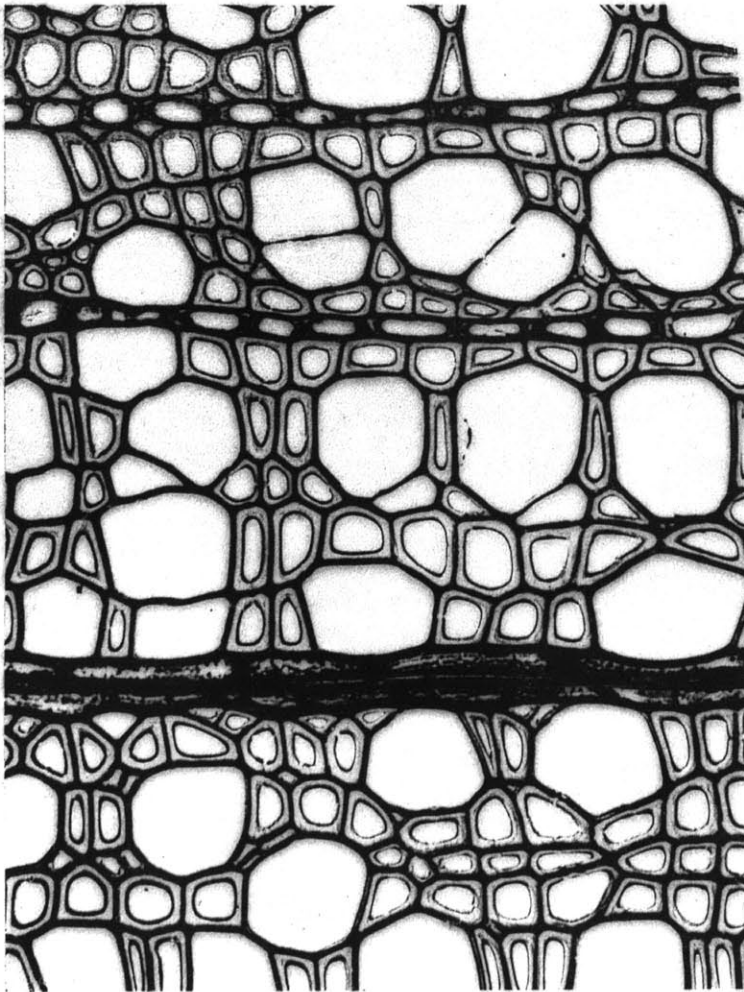
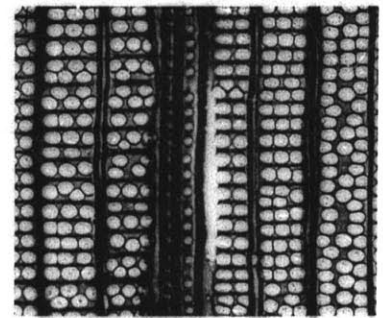
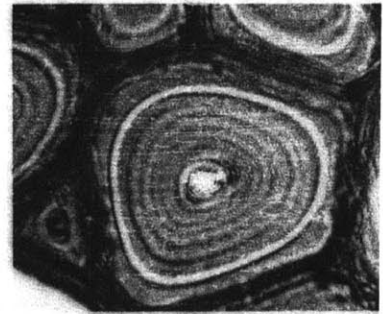
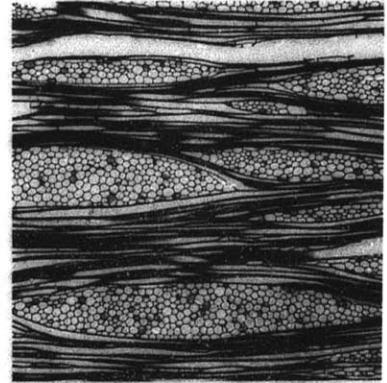
103  
*Transverse Section of Wood, Kadsura Tree*  
 Photomicrograph: Prof. I. W. Bailey, Harvard University

104  
*Tangential Section of Wood*  
 Photomicrograph: Prof. I. W. Bailey, Harvard University

105  
*Tetramerista Transverse Section*  
 Photomicrograph: Prof. I. W. Bailey, Harvard University

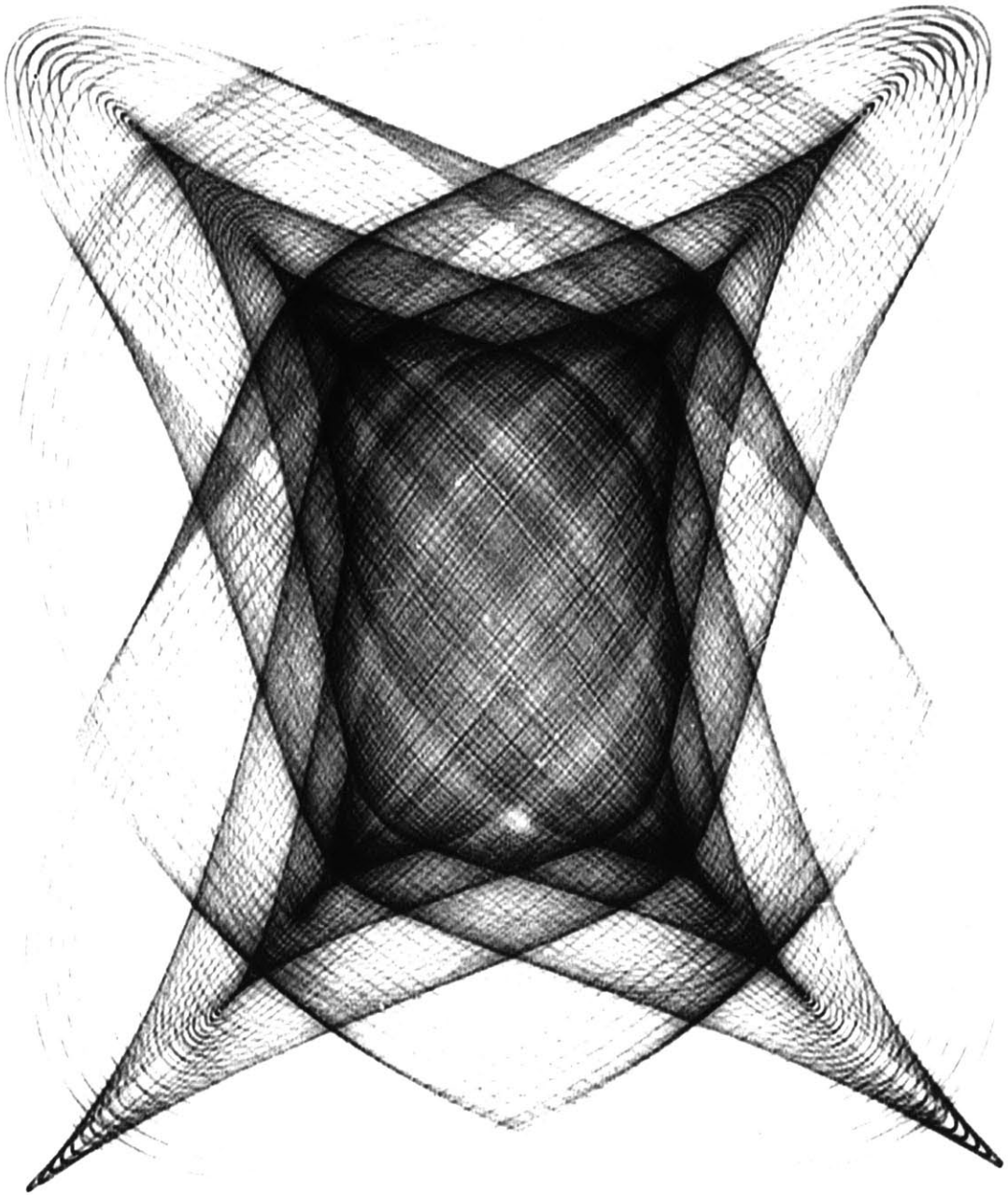
106  
*Sequoia Sempervirens*  
 Radial Section  
 Photomicrograph: Prof. I. W. Bailey, Harvard University

107  
*Triplachton, Radial Section*  
 Photomicrograph: Prof. I. W. Bailey, Harvard University



10  
 10  
 10

Lissajous figure

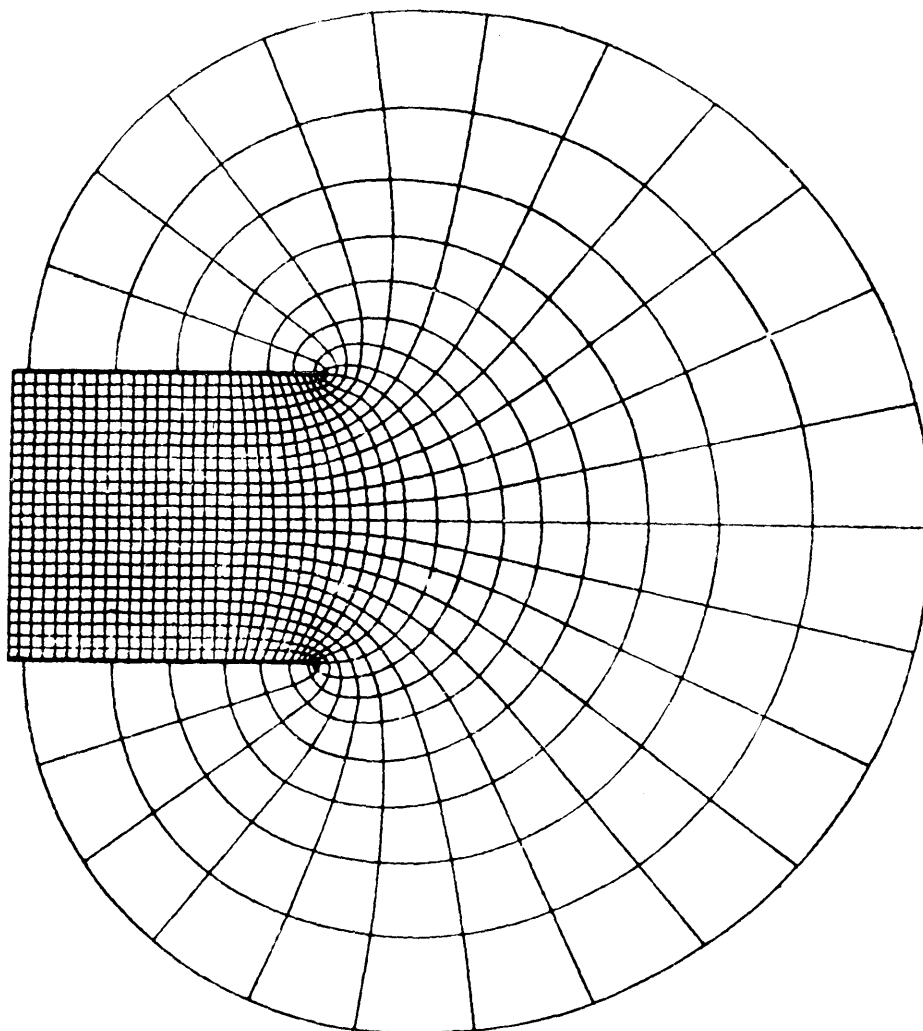




12

*Lines of Force Between Two Plates*

From Clerk Maxwell's Electricity, Vol. 1.

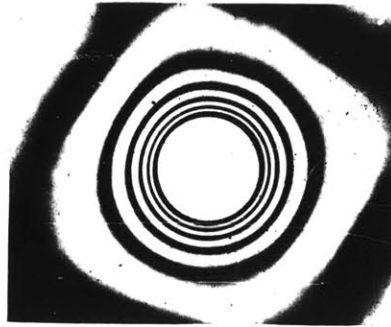


223  
224  
225  
226

*Strain Diagrams*

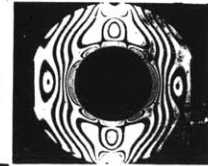
Photo-elasticity Records: Professor W. Murray  
Massachusetts Institute of Technology

Loads proportional to those acting on the actual objects are applied to a scale model made of transparent material, which is then photographed by polarized light. An unstrained model placed between crossed polarized screens appears uniformly black under these conditions. Whenever stress occurs, the refractive index of the material is altered and bright lines will appear which contour the principal stresses.



225

227  
*High Pressure Chamber Loci of Equal Shear Stresses*  
The Franklin Institute

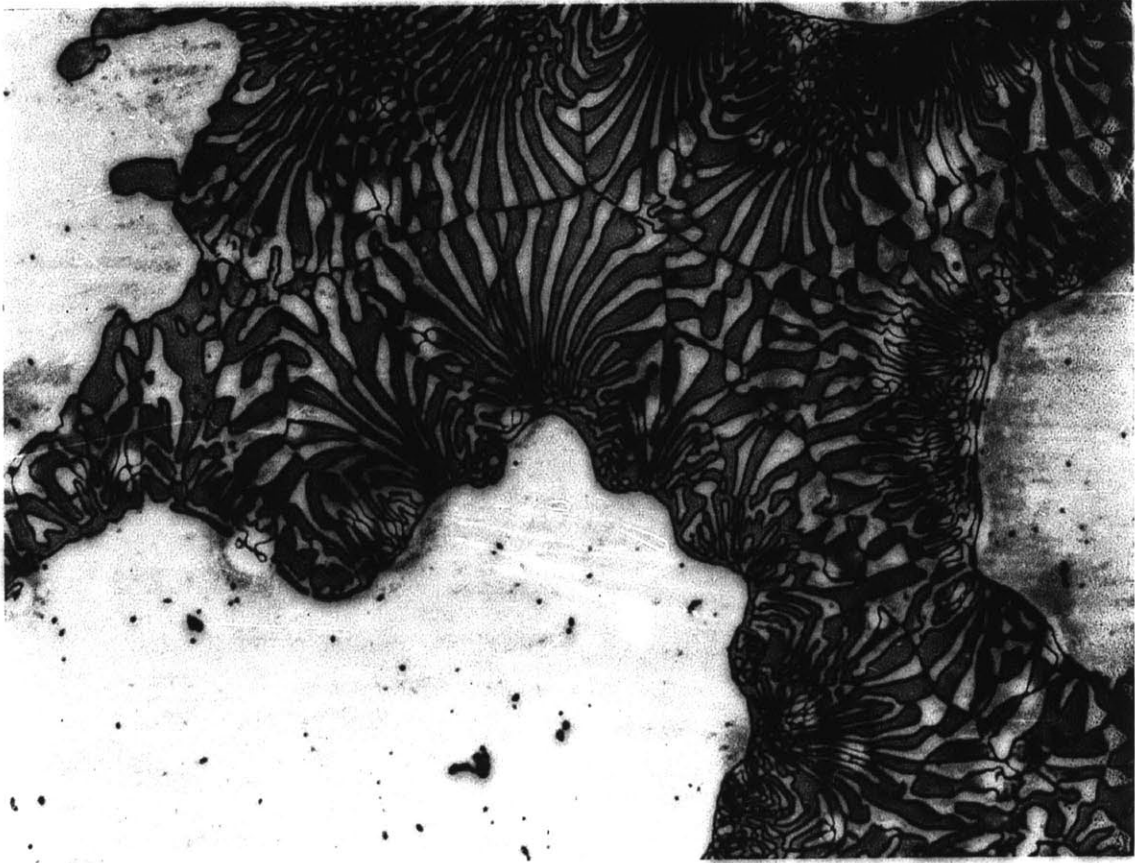


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226



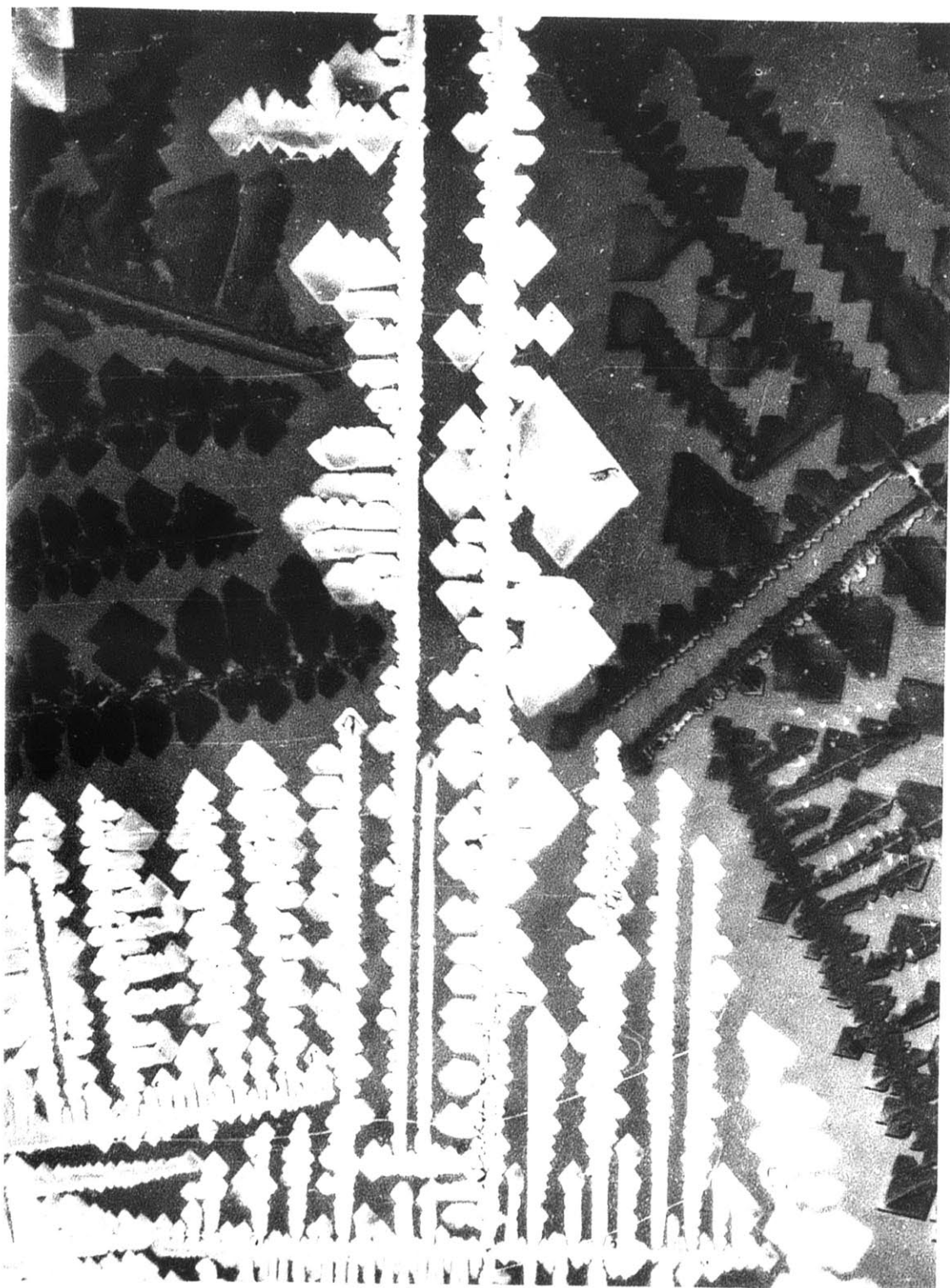


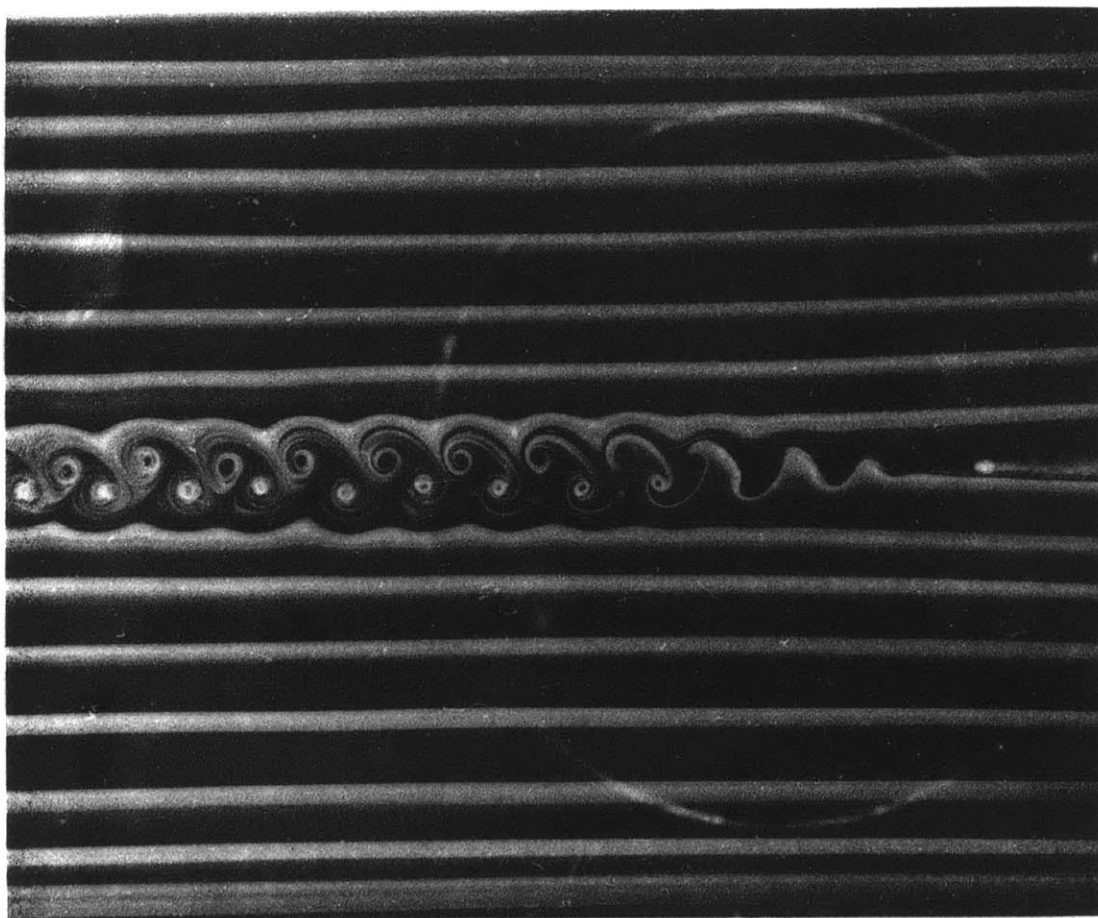
136

*Beryllium + 3% Iron.*

Photomicrograph: H. P. Roth, Massachusetts Institute of Technology

Crystal growth, chlorcalcium

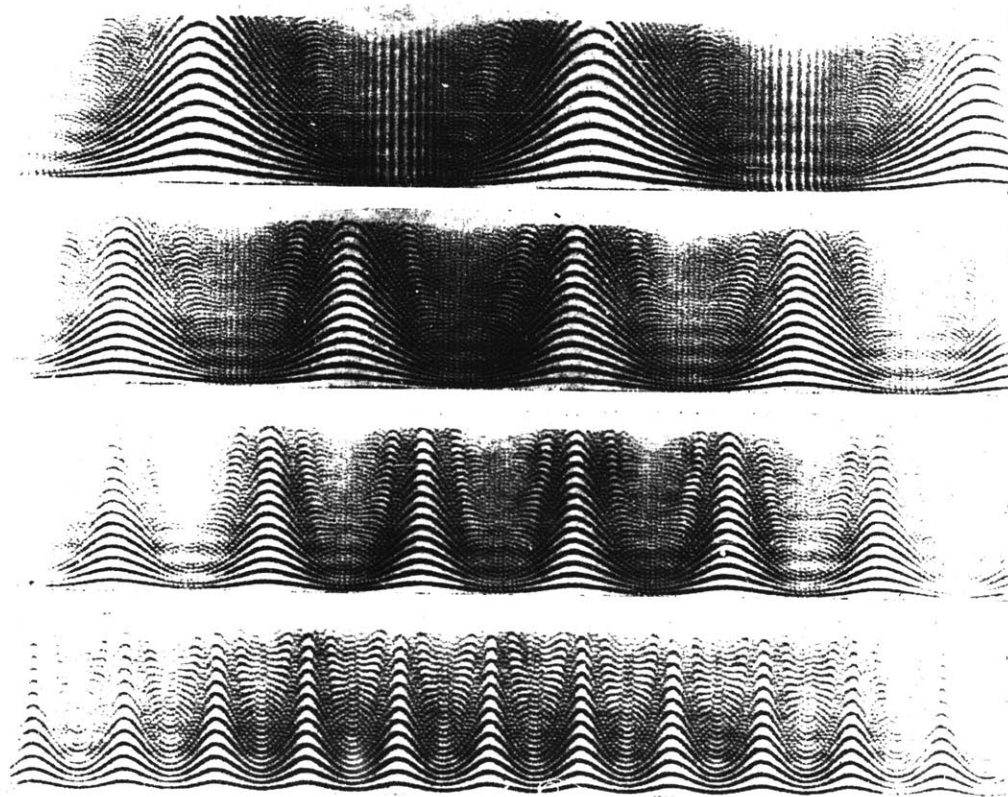




229

*Mid-span Wake of an Airfoil of 18 inch Chord at 33 feet/sec.*

Courtesy of Prof. F. N. M. Brown, University of Notre Dame

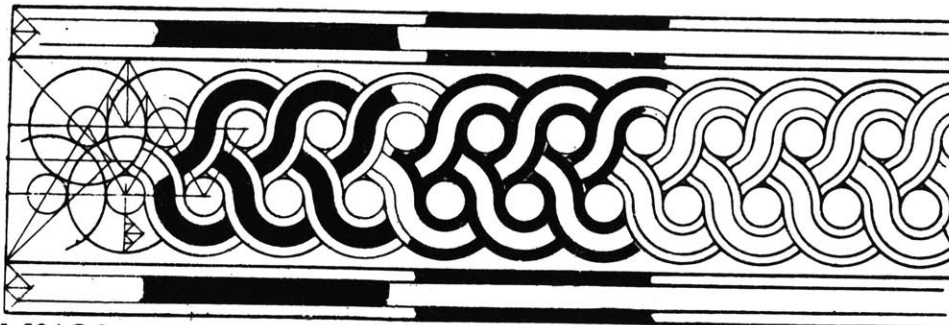


194

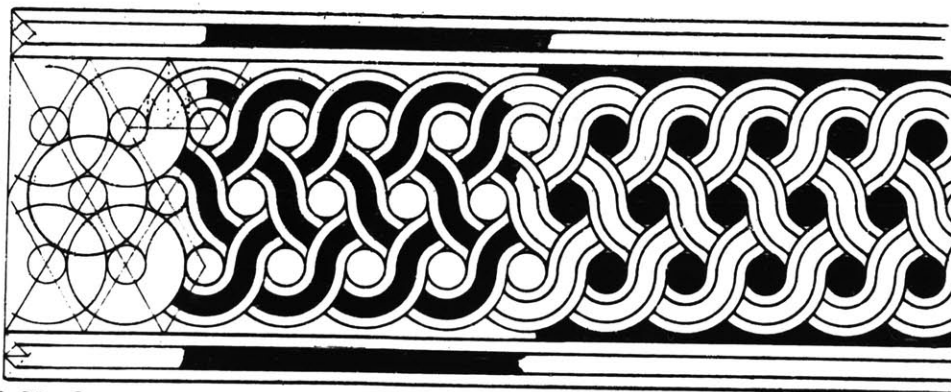
*Frequency Modulation Series*

A complex wave rich in harmonics is varied in frequency at several rates  
Courtesy of R. K. Potter, Bell Telephone Laboratories, Inc.

## Geometric decorative patterns



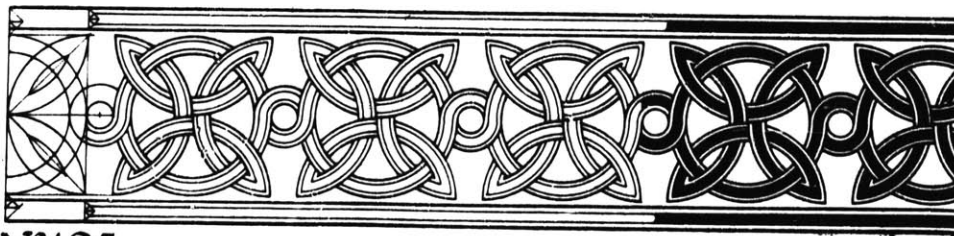
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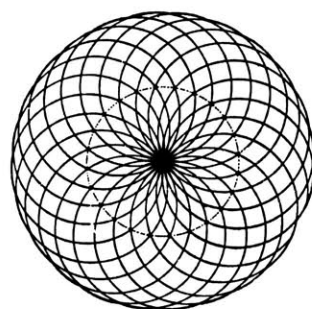
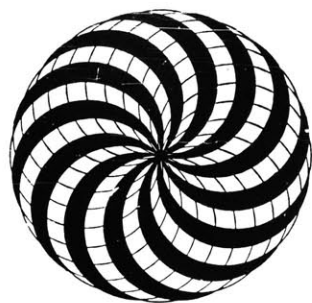
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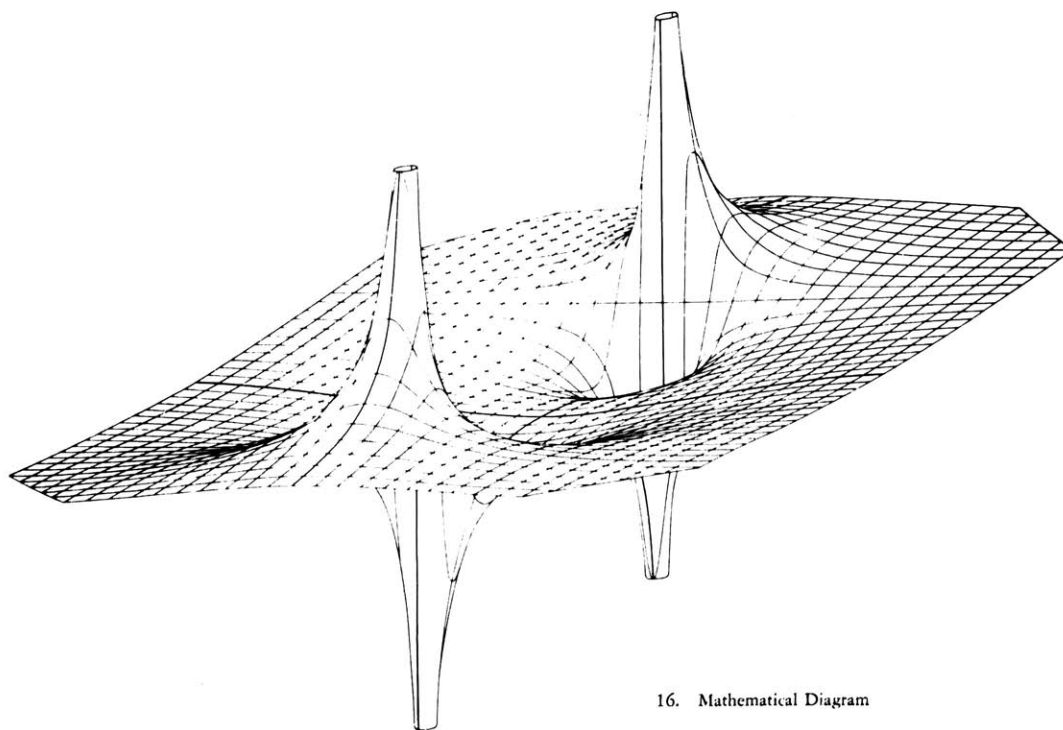
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15

*Variation of a single geometrical motive.*  
 The movement of a circle whose center  
 is carried along the circumference  
 of another circle.

Herman V. Baravalle  
 Scripta Mathematica Vol. XVIII.I



16. Mathematical Diagram



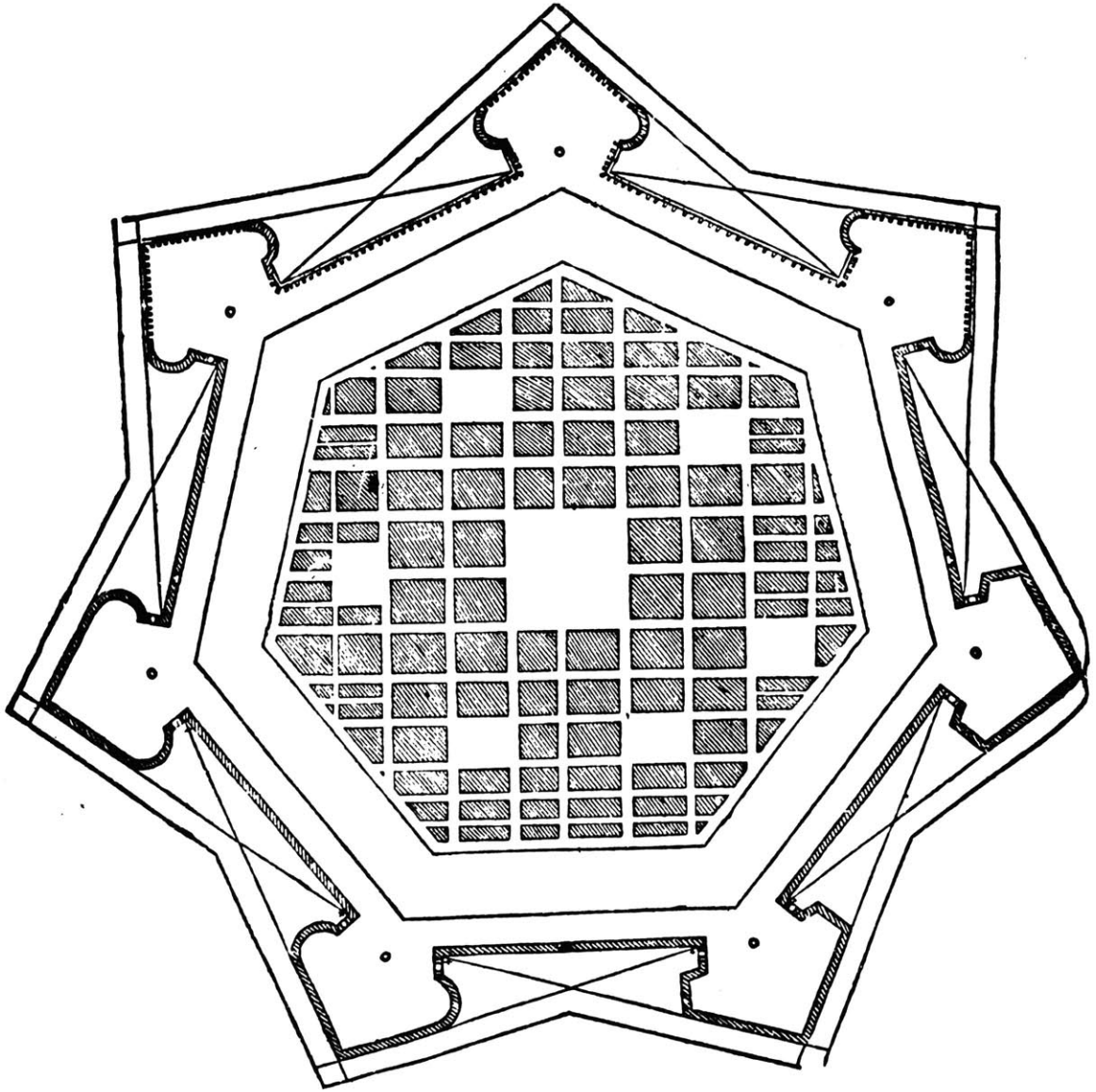
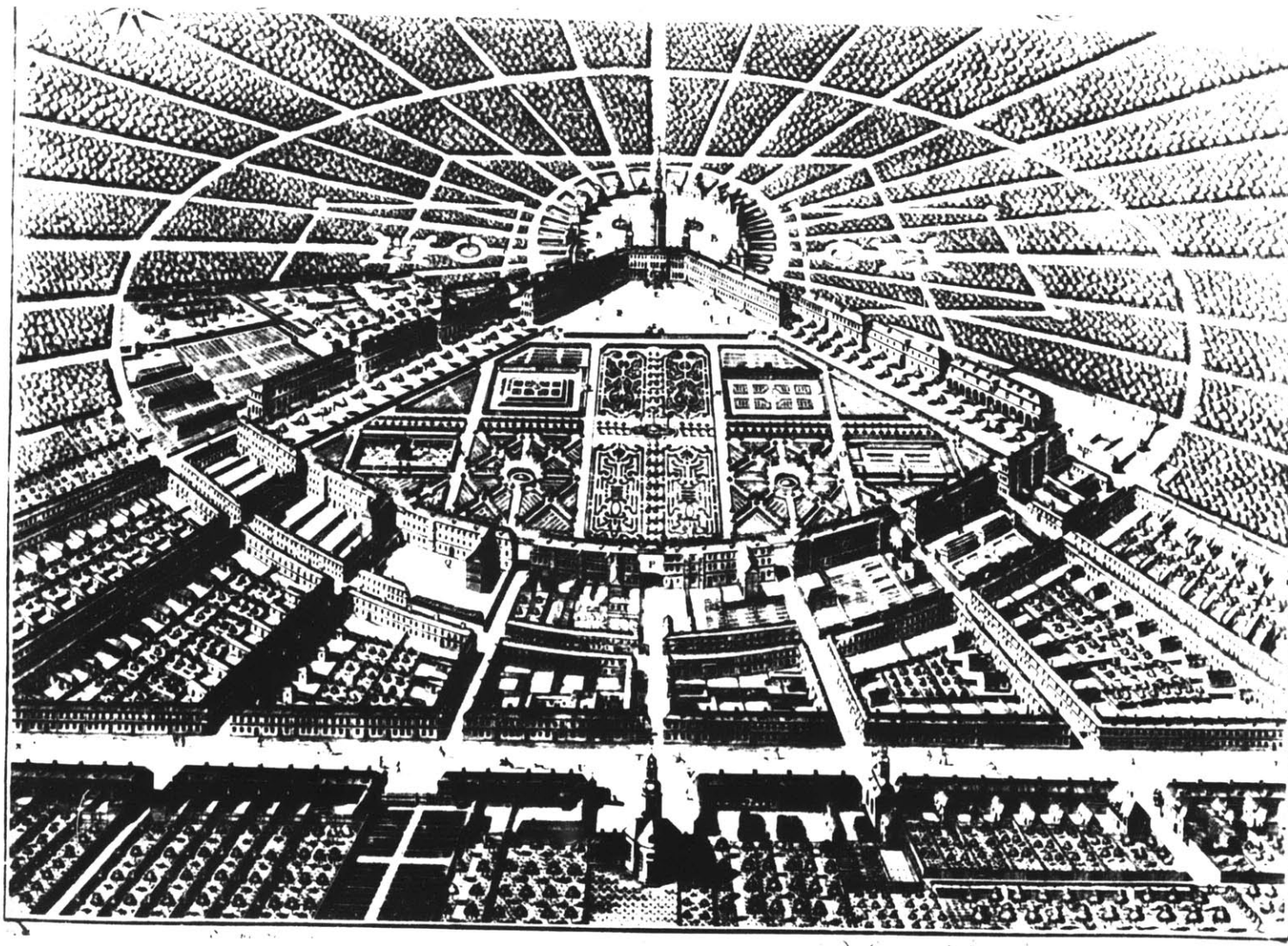


Figure 10.—Cataneo: Ideal City.



Stadtplan von 1739, aus der Zeit der Stadtgründung. Der Schloßturm ist Blickpunkt von neun Radialstraßen, weiter von 23 Waldalleen, erstere nach Süden.  
(Foto: Bildstelle der Stadt Karlsruhe)

### III. SYSTEMS AS APPLIED TO CONSTRUCTION AND ARCHITECTURE

Systematic thinking has been used in construction and architecture throughout history. Recently, conscious attempts have been made to apply systems to architecture. Modern buildings embody a number of systems. These are structural, spatial, and mechanical systems. The location and functional inter-relationship of structural elements can form a regular and consistent pattern. The relationship between varied spaces in a building, the progression from the exterior into the interior, and the subdivision of the total area into functionally and spatially differentiated parts form a hierarchical organization. The exterior, or visual appearance of the building should conform to and express the structural and spatial systems.

Complex mechanical systems have been introduced into buildings. They enable man to control the immediate physical environment more effectively.

All of these systems combine to form a complete building. Thus the building must be the result of the integration of the subsidiary systems. It should form a pattern which is the direct result of and which reflects this integration. Modern buildings should satisfy all the requirements of life. As these change and/or grow, the building also must change or grow. Thus a pattern of adaptation and growth must be built into the total building system.

Many examples illustrating the use of systems in construction and architecture can be cited. In most of these, the structural elements are systematized into a consistent pattern. Some concentrate on the application of new materials to construction

systems. Others concentrate on systems of assembly. They investigate various methods of prefabrication and the application of these methods to varied buildings. A third group manipulates the structural elements to develop light and long span structures based on the repetitive use of a minimum number of units. These are generally classified as space frames and are potentially "through" systems. The hollow structure makes it possible to fuse the structural and mechanical systems into the same space.

#### IV. HISTORICAL EXAMPLES OF SYSTEMS IN ARCHITECTURE

##### A. The Doctrine of Durand

J. H. P. Durand was Boullée's student. When Napoleon established the new *École Polytechnique*, Durand was appointed as professor of architecture. He published his lectures as Précis des Leçons in 1802 and 1805. These books made his teachings generally available, and Durand's doctrine had extensive influence in Germany and Northern Europe in the 19th century.

He synthesized and systematized the diverse strands of theory and practice developed in France during the previous 40 years. He dealt as a "constructor" with materials and their proper employment. After defining the goal of architecture, and the structural means and the principles derived from those, he investigated ways of combining architectural elements.

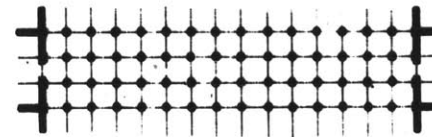
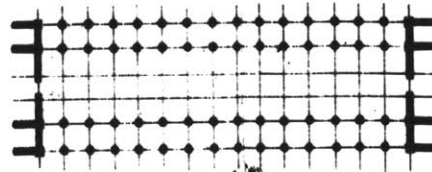
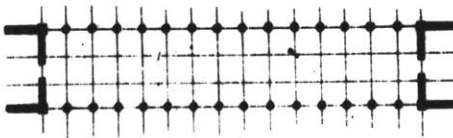
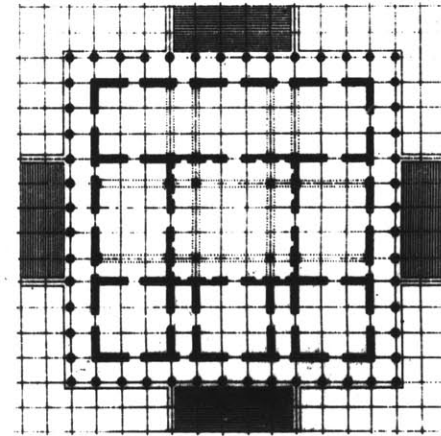
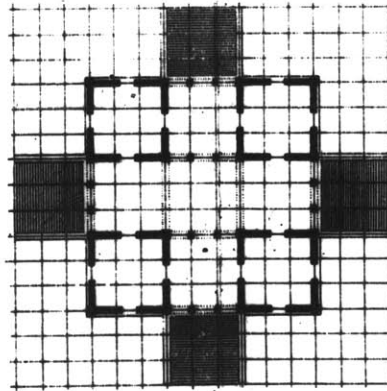
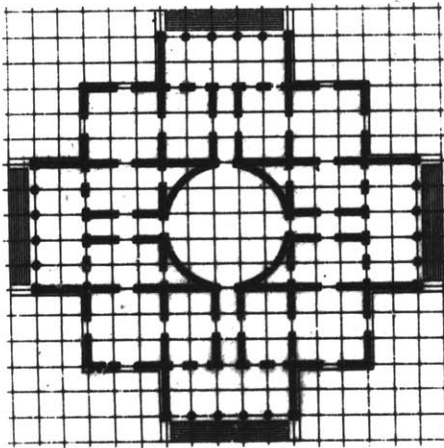
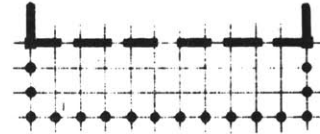
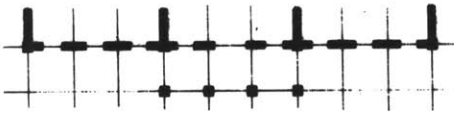
Durand proposed that columns be equally spaced--the spacing being determined by circumstances--and arranged along parallel , equidistant axes. These axes are cut perpendicularly by other parallel equidistant axes. All columns should be placed at the intersections of these axes and the wall along these axes. For the third dimension, these axes should be projected into the vertical plane. Decorative design should be avoided. All plans, sections, and elevations should be designed within the grid lines set by these axes in three dimensions. Durand was interested in varied skylines provided by central and corner towers and in the incorporation of voids in architectural compositions.<sup>1</sup>

---

1. J. H. P. Durand, Précis des Leçons d'Architecture (Paris, 1809); from Part II.

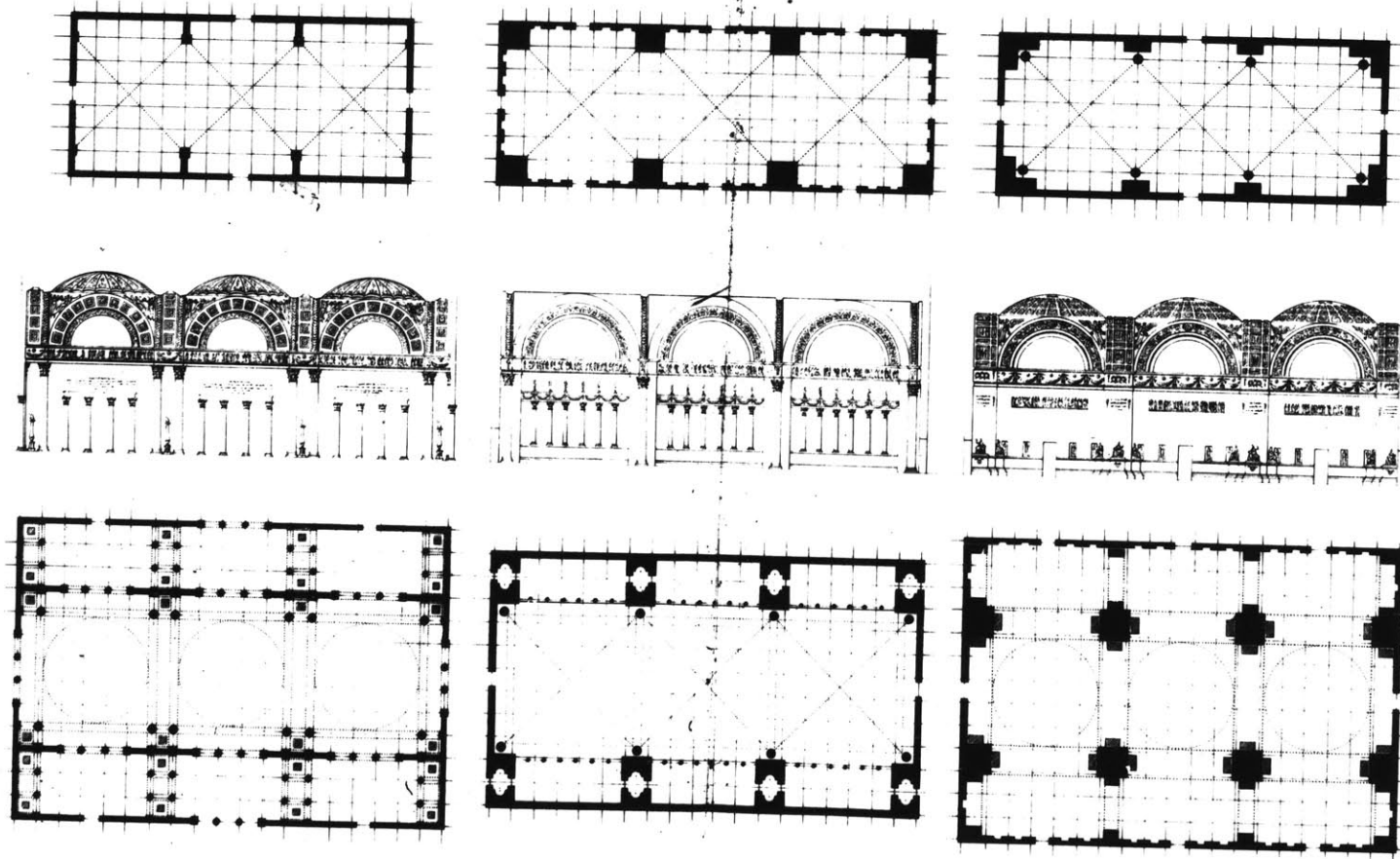
COMBINAISONS HORIZONTALES,  
de Colonnes, de Pilastres, de Murs, de Portes et de Croisées

Planche 1.



dessiné par C. Normand

GALLERIES.



Gravé par C. Normand

## B. The Crystal Palace by Joseph Paxton

The Crystal Palace was designed by Paxton in 1850 to house the first international exhibition in England. Paxton was a builder of glass and iron green houses. He derived his idea of setting the glass into metal frames from the structure of veins which supported lily leaves. He was not interested in specific buildings but in the structural technique and the possibility of its universal application.

The Crystal Palace consisted of cast iron framing members and glass panels set within them. The columns were hollow, and the capital and base were crystallized into mechanical couplings. Three types of trusses were used: cast iron, wrought iron, and wood. They were shallow lattice trusses. The roofing was based on a standard size of glass panel. All connections were standardized and identical.

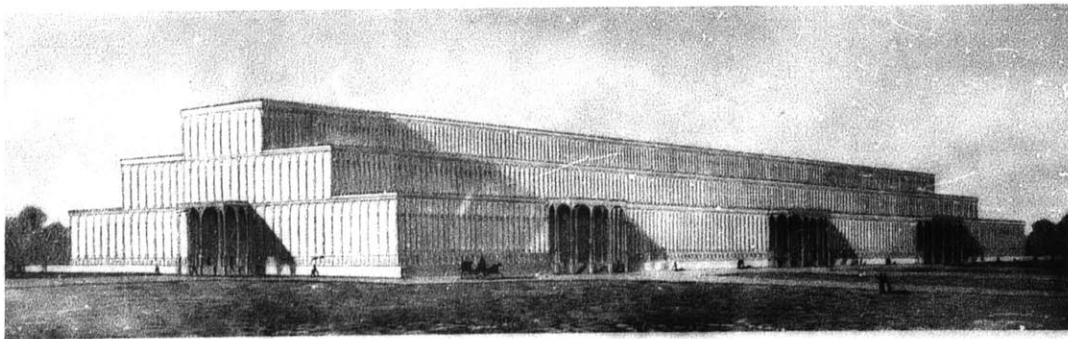
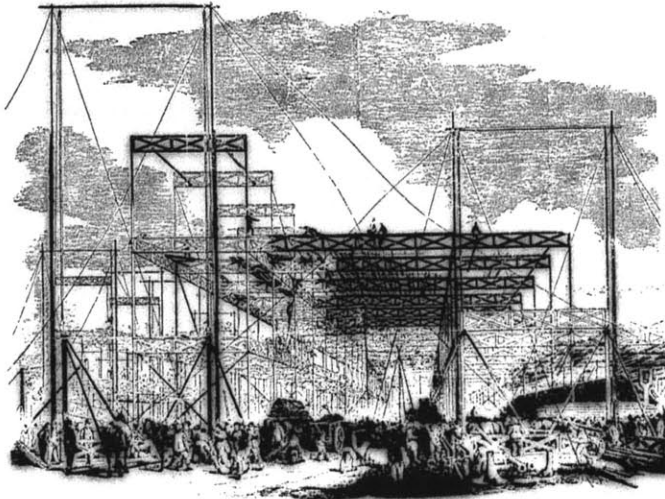
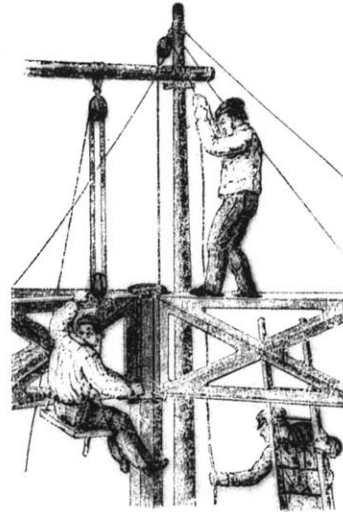
The whole structure was made up of small simple parts and was planned on a modular grid. It enclosed an imposing, tall nave with galleried aisles. The regular rhythm of the structure provided a grid of coordinates defining the space. Full grown elm trees were enclosed within the structure. It was hailed as a technical and architectural achievement at the time. The building was 1851 feet long, yet it was erected in less than four months.<sup>2</sup>

---

2. Konrad Wachsmann, Wendepunkt im Bauen (Wiesbaden, 1959), pp. 12-19.



Joseph Paxton <sup>154</sup>  
 Crystal Palace of the International  
 Exposition, London,  
 1851.  
 Contemporary wood engravings  
 of the planned structure (c) and of  
 the prefabricated elements during  
 assembly (a & b).



### C. The Unistrut System

The goals of the system are to achieve durability, flexibility, expandability, demountability, and reusability. It is geared to mass production techniques and consists of standardized and interchangeable parts.

"In the Unistrut space frame the members form the edges of alternating erect and inverted pentahedrons whose bases create two parallel planes and whose sides create a series of tetrahedrons which interlock with the pentahedrons. For economy in production, handling, and erection, all framing members are identical and are assembled with identical connectors so designed as to require only one bolt at each end of each member."<sup>3</sup>

---

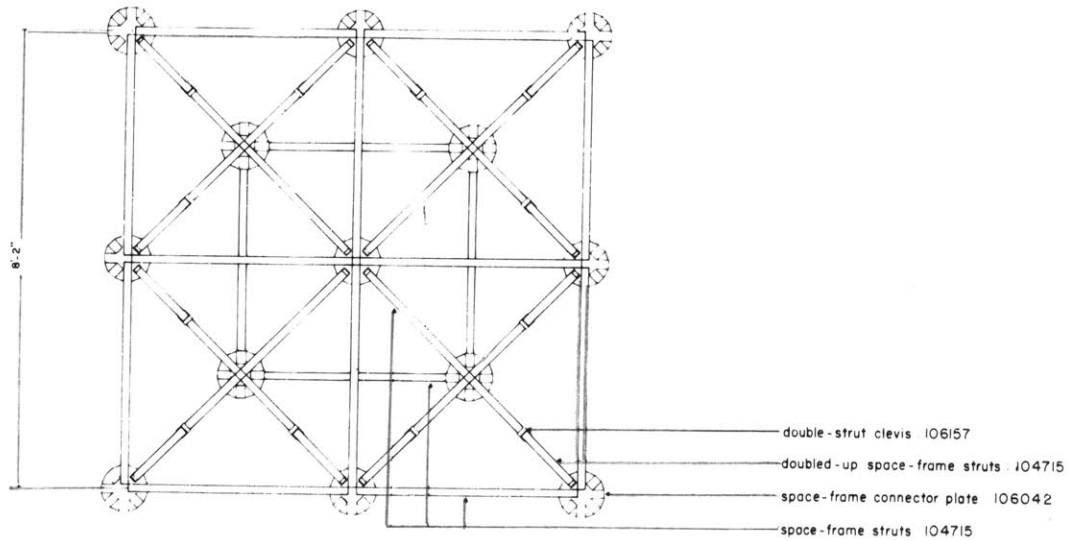
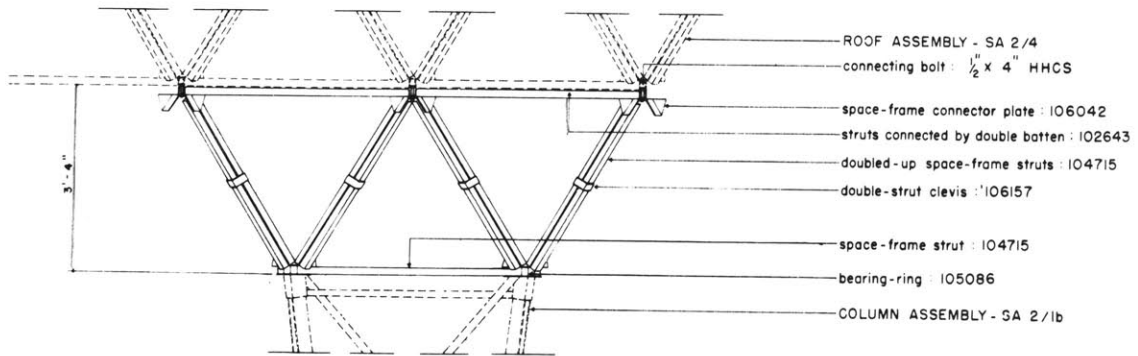
3. Paul Coy, Unistrut Space-Frame System (The University of Michigan, Ann Arbor, 1955), cover page and p. 1.

✓ FRAMING SYSTEM  
COLUMN CAP ASSEMBLY

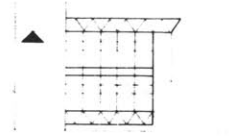
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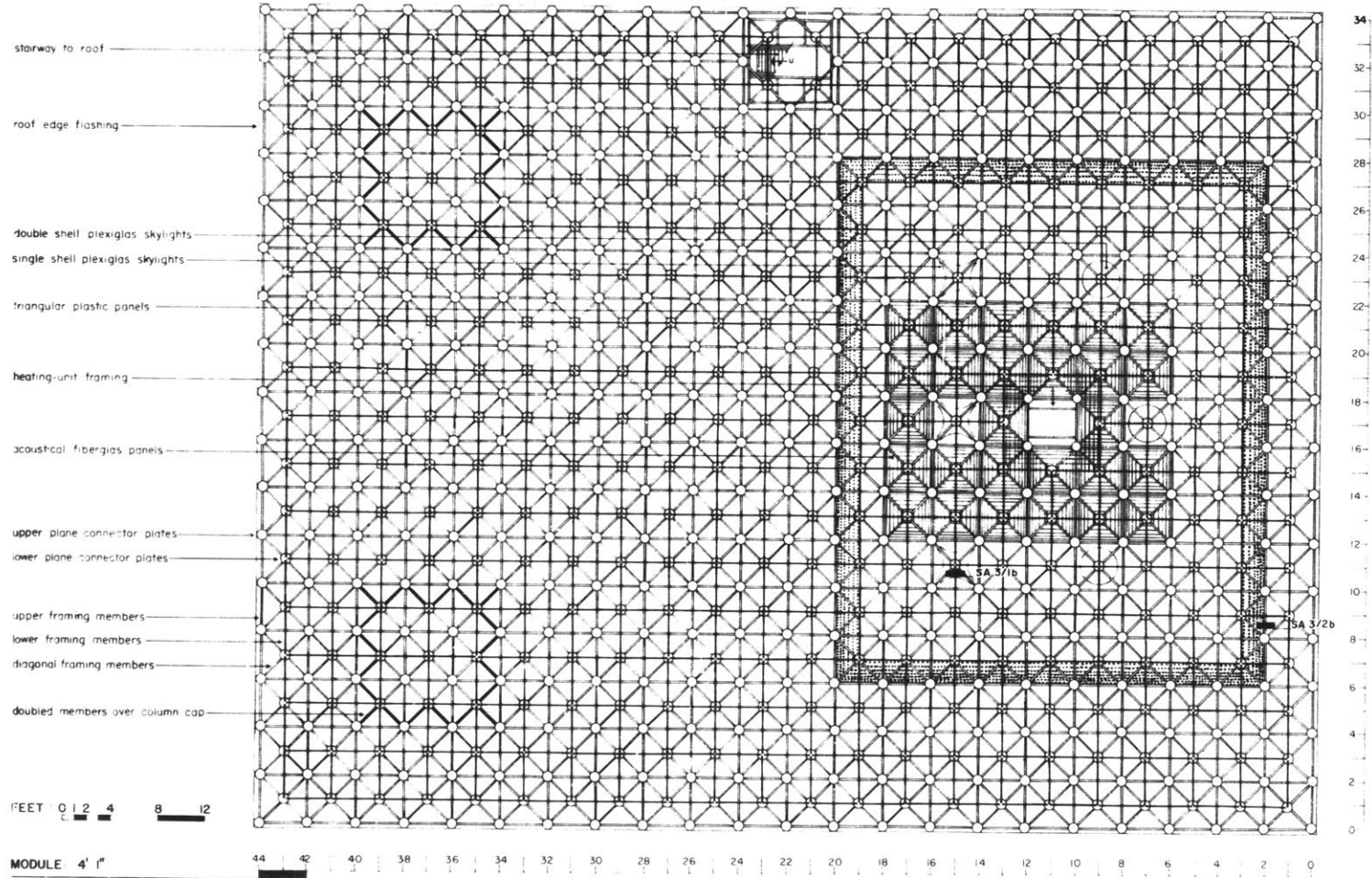
0 1 2 3 4 FEET



BD 3/A4 \_\_\_\_\_ ENCLOSURE SYSTEM  
PLAN - UPPER LEVEL CEILING (I)



U of M Research Lab

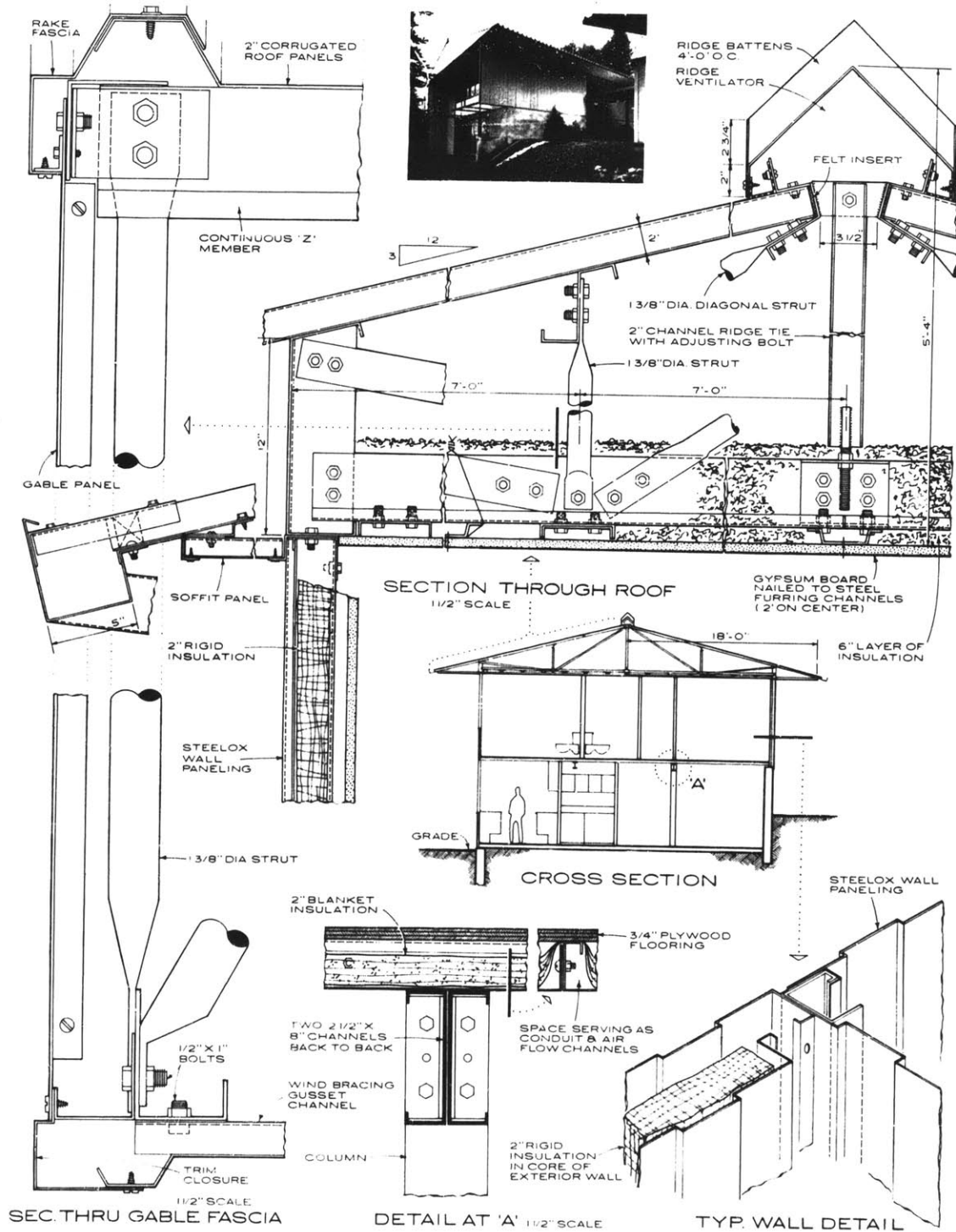


#### D. Prefabricated Steel "Techbuilt" House

The system designed by Carl Koch has the following steel components: (1) an exterior wall system of prefinished panels where the ribbed design eliminates the visible joint between the interlocking panels, (2) a window wall system of C-sections that can frame fixed or sliding glass and a variety of wall panels, (3) stressed-skin roof truss with roof sheet of heat reflecting aluminized steel, and (4) intermediate floor-ceiling with integral air distribution.<sup>4</sup>

---

4. "Prefab-Steel'Techbuilt' , " Progressive Architecture, February, 1963, pp. 154-157.



PREFAB-STEEL TECHBUILT HOUSE: Yorktown Heights, N.Y.  
CARL KOCH, Architect

SELECTED DETAIL  
FRAMING COMPONENTS

## E. CLASP

An English system of prefabricated component parts for school construction was designed in 1957. It is called CLASP, which stands for the "Consortium of Local Authorities, Special Programme."

The components are factory-produced on a 3'-4" module with an almost unlimited range of combination possibilities permitting the architect wide latitude in actual design. This module adequately meets the different requirements in educational buildings, yet is not so small as to present complications in manufacturing or assembly. External walls can change direction at intervals of 6'-8" and 10'-0", or any combination of these two dimensions. Steel columns can be located at any intersection of the 3'-4" square grid; partitions are centered on the grid lines with changes in direction possible at 3'-4". Window sills are at 2'-0", 2'-8", or 3'-4" above the finished floors. Transoms and door heads are at 6'-8", and floor to ceiling heights can be at 8, 10, 12, 14, or 16 feet.

Factory made components in the CLASP system include steel frame units, parts for the heating system, precast concrete panels, window frames, aluminum sliding windows and ventilating louvers, finished rubber floors, eave units, roof lights, light-gauge steel panels, internal doors, prefabricated partitions, and sanitary fittings.

Savings provided by the use of this system come from letting of contracts

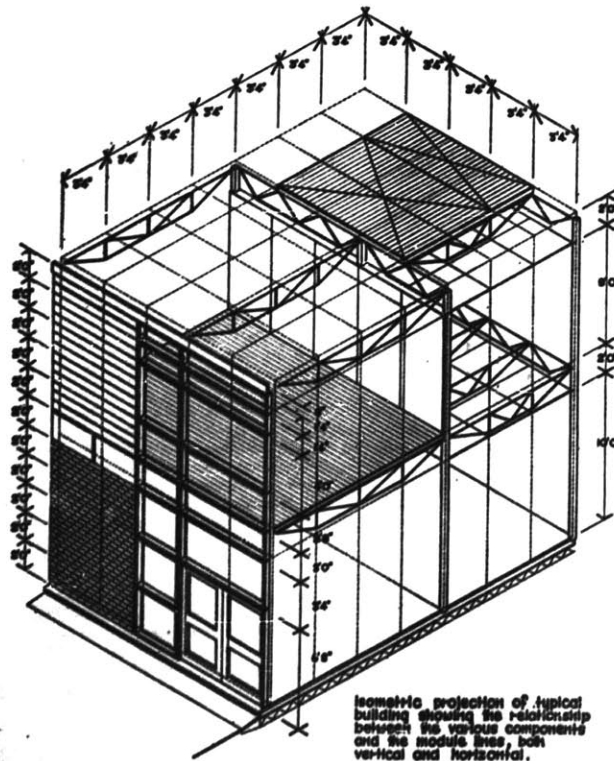
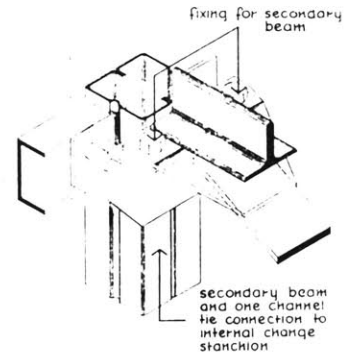
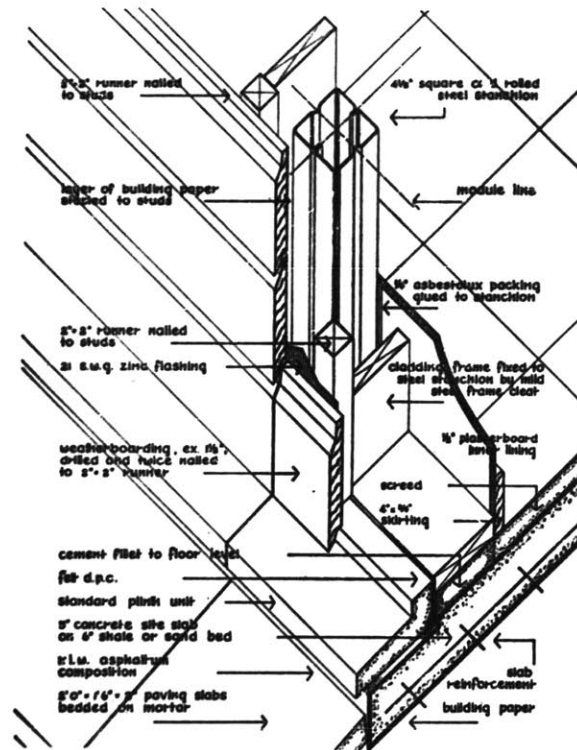
on the basis of the estimated quantities for all the buildings in the annual program. The manufacturer can run the complete quantity ordered all at once or produce in times of slack, and stockpile.

The consortium continues to invest one-fourth of one percent of its gross yearly construction expenditure in research and development, to further improve the system.<sup>5</sup>

---

5. "New Proposals to Cut School Costs," Architectural Forum, November, 1961, pp. 117-118.





CLASP schools are set on concrete slabs varying from 5 to 8 inches thick. One requirement in their design was to accommodate some ground movement because many must be erected in old mining areas. For this reason the vertical columns are pin-jointed, and are stabilized by spring-loaded diagonal wind braces. Also for this reason, window frames are wood (Swedish redwood) although sash are aluminum. At left is a diagram showing typical column and slab meeting; above, the typical column head. All columns are square. All components are kept comparatively small and light to avoid the necessity for large machinery to handle them on site.

Diagram at lower left indicates the vertical flexibility of the system, and typical details are shown at the top of the facing page. (Eaves gutter is drained through a prefabricated rain-water head fixed to the fascia.) Below, opposite, is the window schedule for the CLASP system, totaling 50 sizes, with a vast possibility of combinations by the local school architect. About 150 standard drawings are issued to show the components and assembly details of the CLASP system, so architects need spend only half as much time on production of drawings.

CLASP can be built to a height of four floors, and has been used for other building types besides schools. The British War Office Computer Building in Winchester (right) was assembled from these same components. Drawings here are from British Ministry of Education Building Bulletin 19, The Story of Clasp, obtainable (price 95 cents) from Sales Section, British Information Services, 45 Rockefeller Plaza, New York 20, N. Y. Other British building bulletins may be secured from the same source.

## F. Building Systems Developed by Konrad Wachsmann

Konrad Wachsmann is interested in the mechanics of building, in mass production techniques, prefabrication, and the industrialization of the building industry. One of the great virtues of industrialization is the ability to manufacture uniform, peak quality products. This process can have its full effect only through standardization. Industrialization of the building industry requires the prefabrication of building elements, or standardization of building parts into articles which can be mass produced. Thus building becomes a question of assembly. The prefabricated parts must conform to a system of modular co-ordination. And such parts must be capable of producing buildings where all the complex mechanical and electrical services and equipment are integrated with the structure. Only such buildings can provide perfect environmental control and satisfy all the requirements of the age. This integration is to be achieved through the coordination of modules. Wachsmann defines these modules as the material, performance, geometry, handling, structural, element, joint, component, tolerance, installation, fixture, and planning modules. In a system of assembly, joints and connectors are of utmost importance. They are the essential formative elements in the system. They indicate zones of contact and define any object they enclose. Adoption of a particular joint depends on technical considerations and on the nature of the problem. "Connectors may be independent mechanical systems, . . . , or they may be formed directly from the material of the structural member itself, . . . ,

or they may be independent key elements, forming numerous individual pieces, first assembled with the structural members on the site."<sup>6</sup>

Wachsmann developed a partition wall system, a building panel system, a mobilar system and a space structure. In all of these, the joint is the key element. In the partition wall system, a joint with a constant profile which connects twelve elements in a single point is developed.

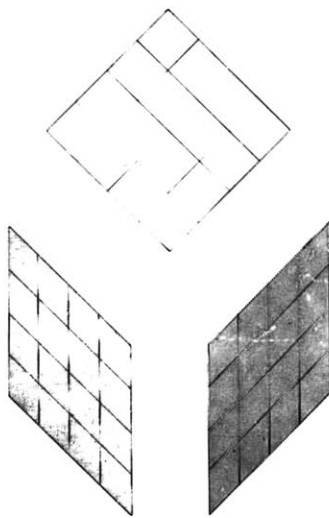
The building panel system was developed in collaboration with Walter Gropius. They developed a frame section based on an axial modular raster. These sections were joined with a hook type metal clip. They selected a 40" planning module and a 4" internal module based on the study of sizes of fixtures and dimensional requirements of building elements. Then they developed a system of plumbing assembly and electrical installations to be built into the panels. They distributed the switches and receptacles into a system of fixed points determined by the module.

The mobilar system is a tubular steel design. The problem was to use "the advantageous statical properties of tubular cross sections in steel construction." This led to the development of a new truss joint and a movable wall panel assembly. In the Mobilar system, tubular members of various standard lengths are used. These have offset eye plates welded at each end and they can be assembled in any combination of truss, purlin, column, and so on.

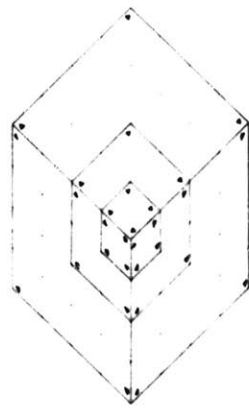
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6. Wachsmann, p. 90.

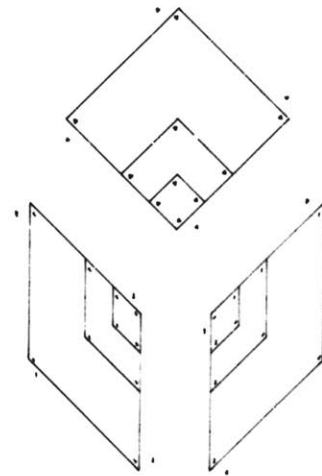
Wachsmann then was commissioned to design a space structure (for building hangers) by the Air Force. The problem was to design a prefabricated, demountable assembly system which could be combined into buildings of any size or shape with a minimum number of joint types. He developed a universal connector which closed around the main members like a ring from which secondary members radiated in all directions, in any combination, and at any angle. The connector was composed of five standard elements. Tubular sections and cables were used as structural elements.



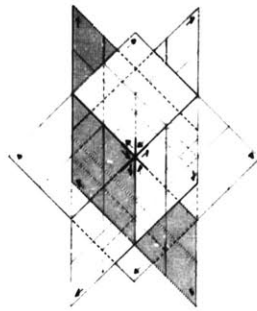
69 Die Separierung der Würfeloberflächen in drei getrennte, aber untereinander abhängige Ebenen



70 Die Bewegungsbeziehung der Einzelteile, in denen sich beliebig unterteilten Kubus



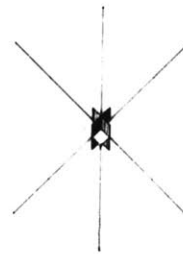
71 Die separierten Ebenen des Kubus, nun zur Kombination von Dimensions- und Bewegungsbestimmung geworden, bedingen die Zeit als zusätzlichen notwendigen Faktor zur Bestimmung von Maßwerten



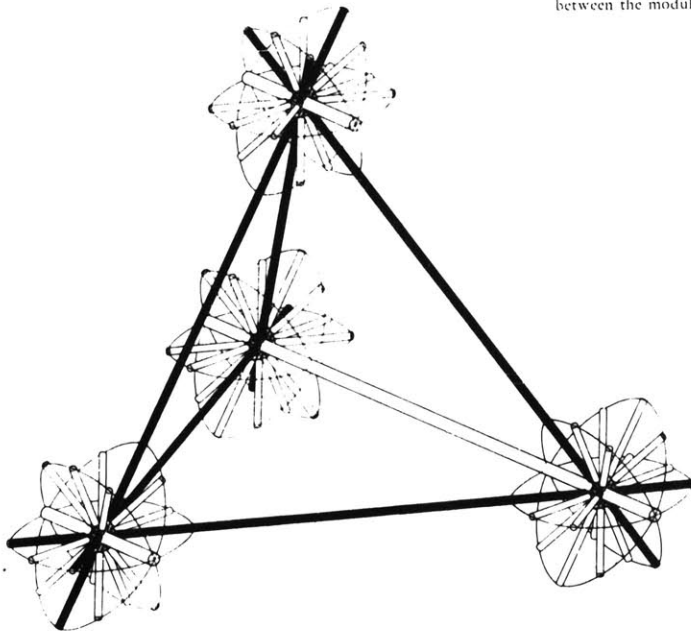
73 Die räumliche Durchdringung der modular bestimmten Flächen eines Kubus, identisch mit positiv und negativ, oder konvex und konkav



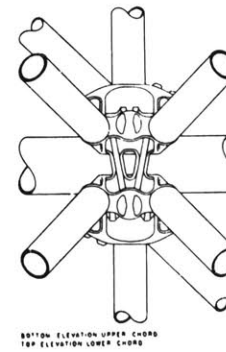
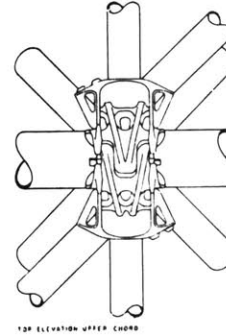
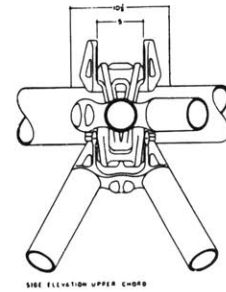
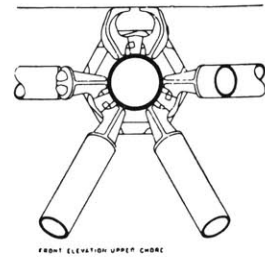
74 Die Bewegungs- und Zeitkontrolle als zusätzliches Ordnungssystem sich durchdringender Flächen

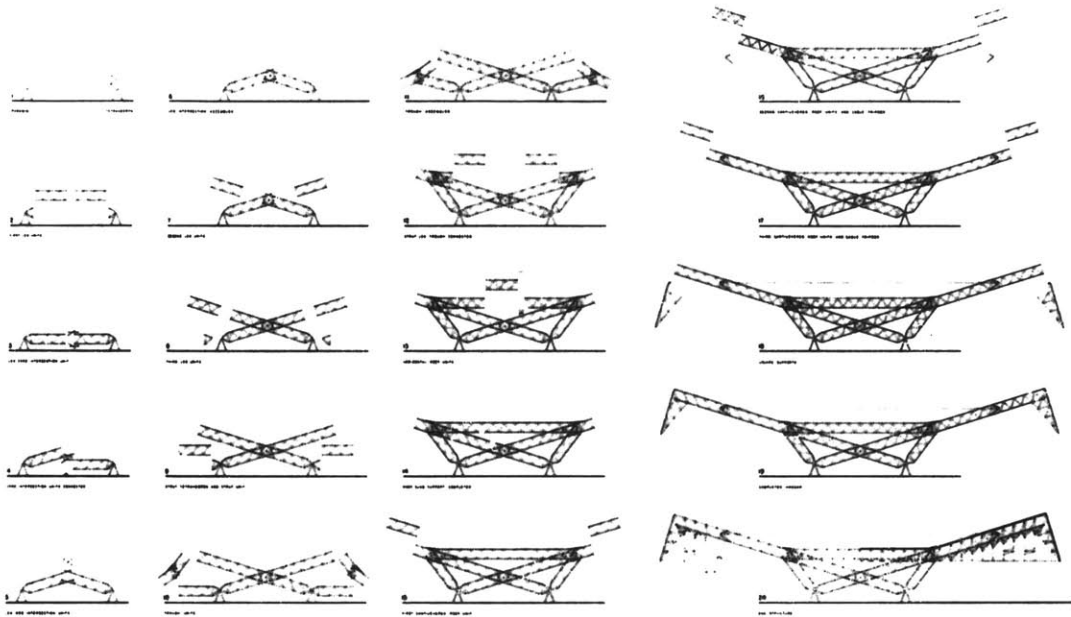


75 Symbol für Maß, Bewegung, Zeit, in das sich jede gedachte Form im System einer angenommenen Beziehung einfügen läßt

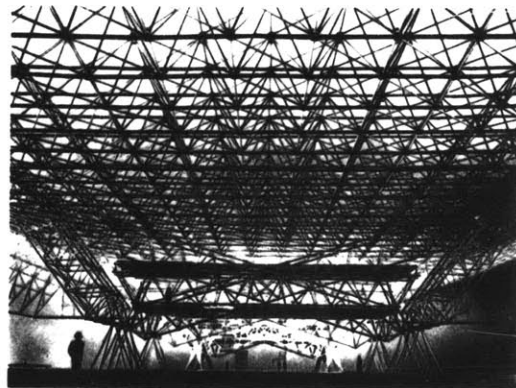


Konrad Wachsmann <sup>155</sup>  
 Structural system for large size  
 airplane hangars,  
 1950-53.  
 a) Standard steel pipe elements  
 (in tetrahedral frames)  
 and their connections.  
 b) Various views of the connectors  
 between the modular pipe sections.





**203** Die Sequenz des Aufbaus der Halle durch die Montage immer gleicher Standardteile ohne Baugerüste nur mit Hilfe von Kränen für eine maximale Belastung von 5 t



**204** Innenansicht in die Längsrichtung der Halle

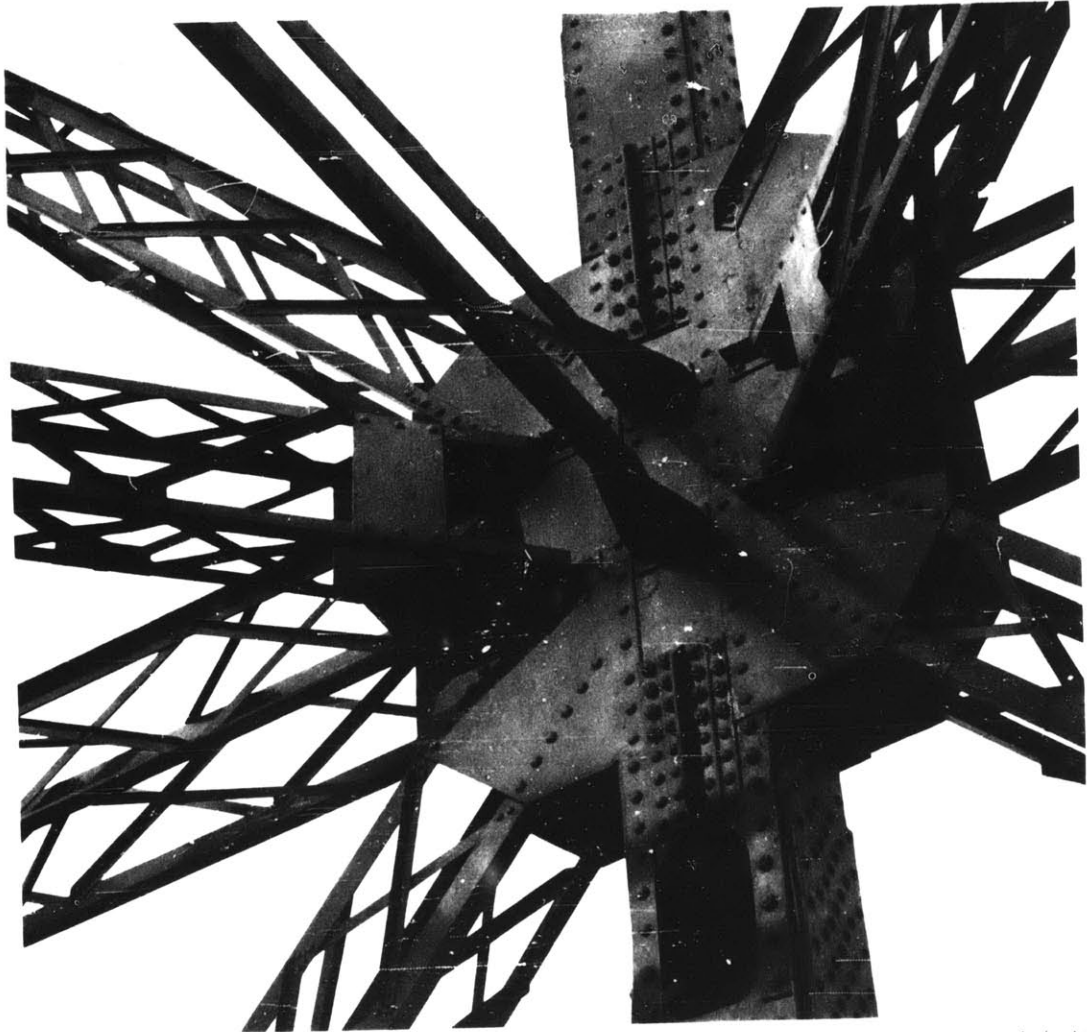
### G. The Eiffel Tower

Gustave Eiffel's tower is a system of heavy struts broken down into fine lattice-work. The systematic use of rivets, small angles, and plates made possible statical effects previously inconceivable. Even though the lattice-work is two-dimensional, the member arrangement system, together with the assembly system, forms a sort of space frame.<sup>7</sup>

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7. Wachsmann, pp. 24-28.





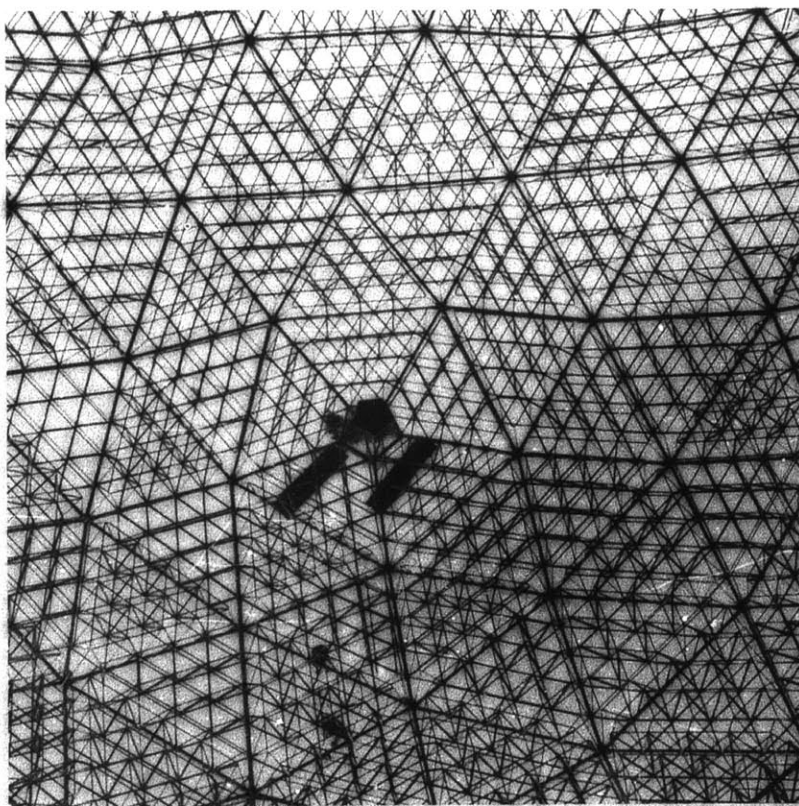
22 Ein asymmetrischer Knotenpunkt! verschieden aufgebaute Gitterträger mit klarer Trennung von Druck- und Zugstäben

## H. Buckminster Fuller's Domes

Since 1922 Buckminster Fuller has been working with structural systems. He uses the term "synergy" to define the way whole systems act as more than the simple sum of their parts. Fuller has developed his geodesic domes based upon the following facts. In an all-motion universe, all phenomenon interactions are precessional: lines of force are not straight, but tend to curvilinear paths. These paths are inherently "geodesic," that is, the shortest distance between points on a curved or spherical surface. With the automatic tendency of energy in networks to triangulate. Fuller assumed the most economical structural energy web to be the fusion of a tetrahedron and a sphere. The sphere encloses the most space with the least surface, and it is strongest against internal pressure. The tetrahedron encloses least space with the most surface, and it is strongest against external pressure. The uses and applications for these domes are enormous.<sup>8</sup>

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8. George McHale, R. Buckminster Fuller (New York, 1962), pp. 29-31.

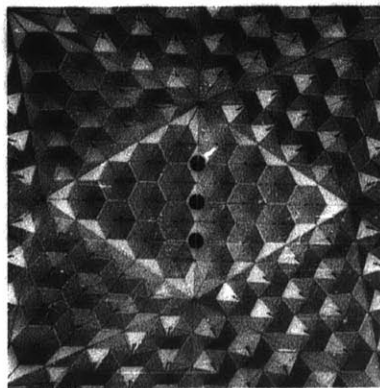
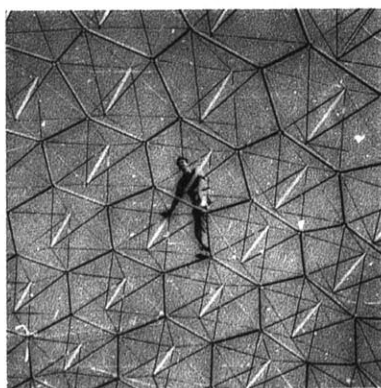


Richard Buckminster Fuller  
"Ford Rotunda" in Dearborn,  
Michigan,  
1953.<sup>160</sup>

View from below of geodesic  
aluminum dome, diameter  
93 ft. 2 in. (left).

Fuller Research Foundation  
Geodesic dome of cardboard at  
X Triennale in Milan,  
1954 (right).<sup>160</sup>

Diameter 36 ft. 1 in.; height 18 ft.



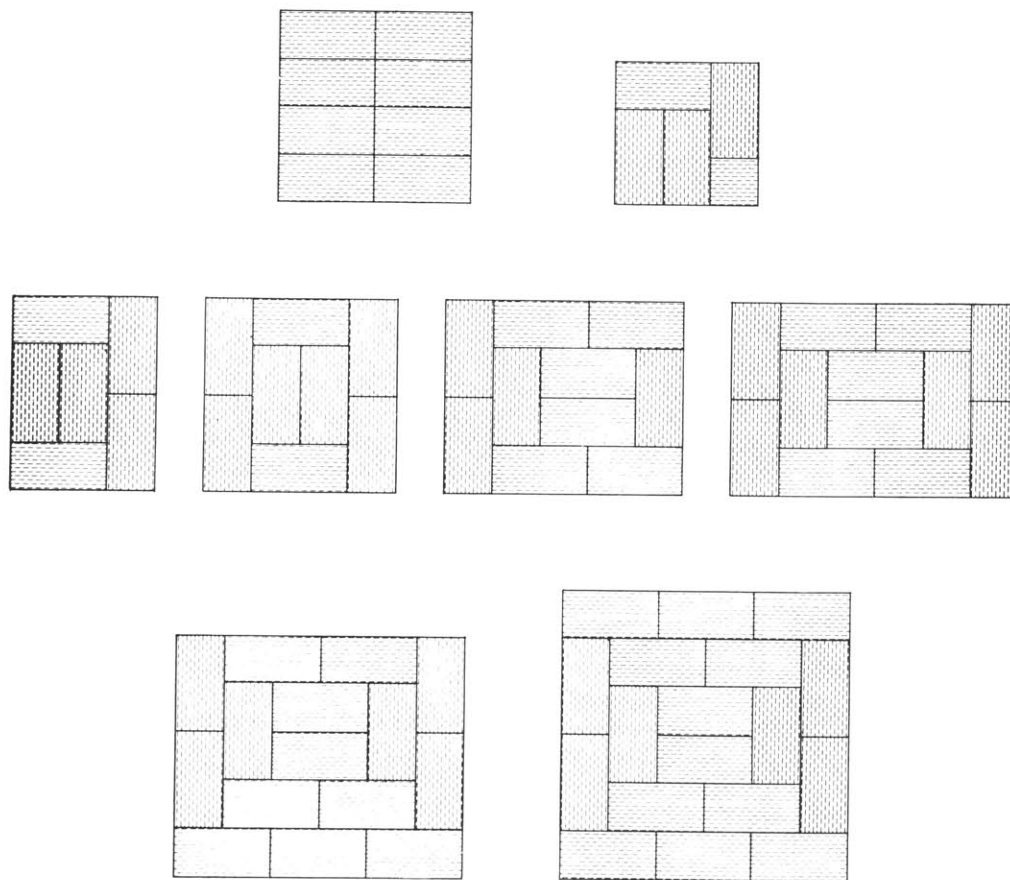
Jeffrey Lindsay, with student  
team.<sup>159</sup>

Dome structure of tension and  
compression members,  
1957 (left).

View from below of the  
experimental model erected in 1:1  
scale (right).

## I. Japanese Houses

A modular system of flexibility is built into the Japanese house. The overall plan and size of the space is determined by the number and arrangement of 3' by 6' by 2-and-1/8 inch rice straw mats called tatami. The space is divided into smaller areas by modular opaque movable screens called fusuma. Similar screens, but semi-transparent, called shoji, are also used when a play of light is wanted. Above the movable screens a system of panels and wooden slats complete the vertical dividers. This modular system of spaces is seen in the Katsura Imperial Villa.

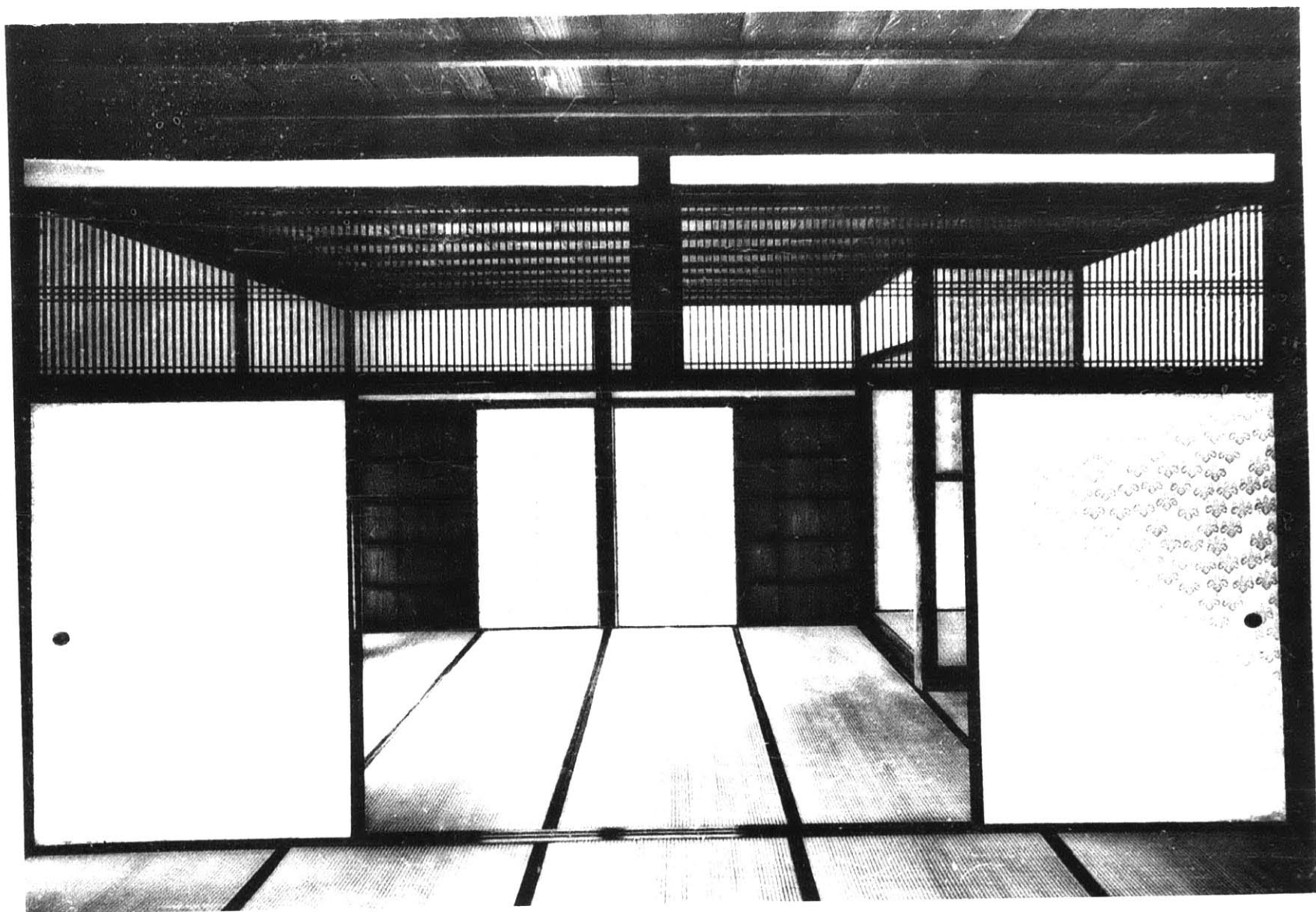


*Tatami* may be arranged in varying patterns to produce rooms of different sizes.

Top row: Left: eight mats arranged in the old formal style usually reserved for temples, palaces, or aristocratic mansions. Right: four and one-half mats, usually used for tea ceremony rooms. A wood panel may be substituted for the half mat.

Middle row: Six, eight, ten, and twelve mat rooms. The mats are arranged to avoid the intersection of four lines.

Bottom row: Fifteen and eighteen mat rooms. The pattern may be extended indefinitely, but the proportions of a room will be limited to those shapes produced by mat combinations which avoid four intersecting lines.



## V. AIM OF THESIS

The aim of this thesis is the development and use of technological and functional criteria as a basis of architectural design--a method that, hopefully, will produce a building expression of enduring quality and usefulness based on a totally integrated system of construction, free from the compromising influences of current fashion and individual mannerism.

The specific problem is the design of a system emphasizing the interdependence between the structural and mechanical components in a research and development building for science and technology, suitable for both academic and non-academic use. By exploring the needs of such a building with its complex requirements, it is felt that the utmost familiarity with the problems involved in solving any building as a total system can be achieved. To satisfy all the criteria for a building of this nature the system will have to accomplish the following: (1) provide optimum initial conditions in terms of space, services, circulation, and environment, while anticipating and facilitating modifications required by changing usage and growth, (2) provide maximum flexibility through the use of large uninterrupted floor areas with a modular subdivision based on illumination requirements, minimum room and corridor widths, and accessibility of utilities; demountability for local expansion; noise and sun control--all as an integral part of a unified solution, and (3) produce a functional building based on logical construction that will obviate obsolescence while achieving all the qualities of excellent architectural design.

## VI. BUILDINGS AS SYSTEMS

The following items explain in detail the components and requirements necessary to organize and develop a building as a unified system.

### A. Permanent and Temporary Systems in Buildings

The permanent systems within a building are those which are expected to remain substantially intact and unchanged throughout the life of the building, regardless of the use in the building at any given time. These would include the structural system, or the basic skeleton of the system, and general service stations which serve the building mechanically. The structural system is formed by the foundations, columns, girders, load bearing walls, structural slabs, exterior walls, and roofs. Core areas complete the skeleton of the system. These core areas include required exit stairs, open stairs or ramps when part of the major public areas or corridor system, elevators and escalators, public toilets, service areas for janitor and maintenance rooms, storage, electrical and telephone closets, and possibly major mechanical service chases.

The temporary systems are those which are expected to, or which foreseeably might change during the life of the building. These would include the partitions, secondary corridors and stairs, mechanical services, lighting, and acoustical control. It is conceivable that the original mechanical system may become obsolete, thus requiring replacement during the life of the building.



## B. Foreseeable and Unpredictable Needs

A research and development building for science and technology functioning as both an academic and non-academic facility must serve many spatial requirements. Laboratories, experimental areas, workshops, construction rooms, and other such spaces require ease of access to the maximum mechanical and utility services provided in the building. In some instances, heavier live load requirements and greater ceiling heights than normally needed elsewhere will be demanded. For some rooms wall space will be more valuable than window area. Freedom from distraction and interference is often of prime importance. Classrooms, offices, lounges, drafting rooms and other similar spaces generally do not have the need for the maximum mechanical services or heavy load capabilities, but do require planning flexibility and greater heights for large lecture halls. They also have the need for freedom from distraction and interference.

Unpredictable needs are, by definition, difficult to anticipate, but it is reasonable to expect that continuing development of science and technology will produce needs that may significantly alter present teaching and research requirements in terms of space and size, amount and complexity of mechanical services and equipment needed. The building system should then be able to accept a maximum number of possible functions and expect modification throughout its life span.

### C. Flexibility

It is the assumption that within the building any existing space may be called upon at some time to serve a different function. It is thus mandatory to achieve maximum flexibility in the total system. To assure this, several premises are set forth including the establishment of a minimum area per floor of 40,000 square feet as a planning requirement, the use of large span structural bays to provide large continuous areas of uninterrupted space, and the centralization of services into cores serving the maximum allowable floor area, thereby consolidating the permanent (non-flexible) components of the system as much as possible.

The structural system should be flexible to the extent that floor to floor heights can be varied within the building, bays or portions of bays can be left out and secondary corridors, stairs and ramps can be introduced into the framework to increase spatial variation within the building.

Except when made an integral part of the structure, the mechanical services should be totally flexible, with the possibility of bringing the maximum number of services into the smallest space expected to need them.

### D. Hierarchy Among the Component Systems

Systems - planning, life, circulation

structural

mechanical

acoustical

Hierarchy among the component systems relates initially to the elements forming the organization of the building as a whole. These include the major entrances, public spaces, interior courts, and major focal points of activity--the cores. Related to these are the lobbies, elevators and large stairs connecting into the major corridors which in turn distribute into the secondary corridors and stairs. Thus a system of planning, life, and circulation is established.

The structural system in turn relates to the overall hierarchy of the building in that the major structural bays and columns establish an overall visual order. The bays are then subdivided into the structural module which establishes the planning order.

Integrated into and relating to both the life of the building and the structural system is the mechanical system. Distribution of the mechanical components is from the mechanical rooms, through major arteries in the cores or by distribution through the supporting structural elements, then into the secondary channels, and finally subdividing into feeder lines which go to the individual modules. Of the mechanical components, lighting and air supply return predominant, with piping, power, and signal lines the lesser elements.

An acoustical control system is still another system which is integrated into the modular sub-system, whereby sound absorption and isolation are achieved.

## VII. SOURCES FOR ILLUSTRATIONS

Page	Source
3	Kepes, Gyorgy. <u>The New Landscape in Art and Science.</u> Paul Theobald and Co., Chicago, 1956, p. 221.
4	Kepes. p. 126.
5	Kepes. p. 176.
6	Kepes. Fig. 12, p. 37.
7	Kepes. p. 193.
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20	Durand. Part II, plate 14.
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25	Larson. drawing BD3/A4.
27	"Prefab - Steel 'Techbuilt' ", <u>Progressive Architecture</u> . Vol. XLIV, No. 2, Feb., 1963, p. 157.
30	"New Proposals to Cut School Costs," <u>Architectural Forum</u> , Vol. 115, No. 5, Nov., 1961, p. 118.
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35	Conrads. p. 115.
36	Wachsmann. p. 183.
38	Wachsmann. p. 27.
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42	Drexler, Arthur. <u>The Architecture of Japan</u> . The Museum of Modern Art, New York, 1955, p. 67.
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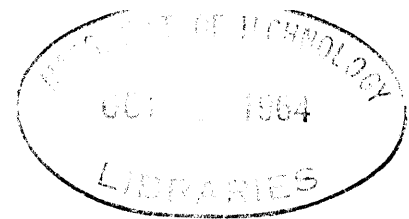
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THE DEVELOPMENT OF A BUILDING UNIT  
WHICH IS STRUCTURALLY AND MECHANICALLY INTEGRATED  
AND WHICH ALLOWS MAXIMUM FLEXIBILITY  
IN INTERNAL REARRANGEMENT AND LATERAL GROWTH

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AT THE

MASSACHUSETTS INSTITUTE OF

TECHNOLOGY

June, 1964

Signature of Author . (accepted in her absence) . . . . .

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Thesis Supervisor

Accepted by . . . . .

Lawrence B. Anderson

Chairman,  
Department of Architecture

June, 1964

Pietro Belluschi, Dean  
School of Architecture and Planning  
Massachusetts Institute of Technology  
Cambridge 39, Massachusetts

Dear Dean Belluschi,

In partial fulfillment for the degree of Master of Architecture I hereby submit this thesis entitled, "The Development of a Building Unit Which is Structurally and Mechanically Integrated and Which Allows Maximum Flexibility in Internal Rearrangement and Lateral Growth."

Respectfully,

Selma A. Hershendorfer



## ABSTRACT

This thesis develops a building unit which is structurally and mechanically integrated. The unit attempts to maximize the flexibility in internal re-arrangement and the possibilities for lateral growth. A prototype building for scientific and technological research is proposed as an illustration of the use of the building unit. The unit is especially applicable to the formation of large buildings or complexes of buildings; however, it does not lend itself to the design of buildings smaller than 300'-0 x 400'-0 in size.

## ACKNOWLEDGEMENTS

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## PROGRAM

The problem is to design a prototype academic building 1-1 1/2 million square feet in area which will be used for scientific and technological research. Spatial requirements and needs for services are varied and expected to change continuously. The only fixed requirements are the code regulations for fire exits and vertical circulation and service cores. 150 ft<sup>2</sup>/person will be assumed. The Live Load is 125 psf. The structure should be concrete and the minimum span should be 40'-0.

Internal flexibility and ability to expand are major considerations. The building should consist of non-specialized spaces which, at any given time, can be used for a variety of purposes. Expansion may occur within the building itself. This refers to shifts in the spatial needs of the various departments in the building. Consequently, it must be possible to repartition large spaces at any time. Another form of expansion refers to the need to expand the total floor area. This may be achieved by vertical and/or lateral expansion.

The demands on mechanical services (i.e., air conditioning, pipes, illumination, communication) will change as the uses of the spaces change. Complete internal flexibility requires that any one or all of these services may be brought to any one space at a given time. And, these services should be so distributed that it may be possible to extend a service to a space without disturbing the neighboring spaces.

## STRUCTURE

The proposed solution is based on the need for expansion. A structurally and mechanically self-sufficient unit is developed in this study. The unit is 100' x 100' square. It is supported on four columns, 60'-0" on center. The structural floor cantilevers 20'-0" from the center of the columns in all four directions. The structural and spatial module is 5'-0" x 5'-0". The structural floor is composed of precast 5'-0" x 5'-0" x 5'-0" elements. These are cross-shaped in plan. Two arms of the cross are solid and two are perforated in such a manner that when the units are assembled, they form a system of waffles consisting of non-perforated waffles surrounded by perforated ones. In other words, every other waffle in the system is non-perforated. Hollow tubes are cast into the floor elements. Post stressing wires are passed through these tubes. Post stressing occurs in two directions and at the top and bottom. Thus the cross shaped sections act as a plate supported on four columns. The periphery of the plate is composed of non-perforated end units through which the post stressing is applied. At the exterior of the building, the exposed ends of the floor units are covered with a fascia. In this case, the post stressing is applied through the fascia. Thus, the fascia becomes integrally attached to the structure. The post stressing plates are then sealed with grout flush with the surface of the fascia.

The solution assumes that the minimum room in the building will be 10'-0" x 10'-0". Therefore services need not be brought to every module to service all

possible spaces. Services are brought to every other module instead. Thus, the mechanical module becomes 10'-0 x 10'-0. An advantage of this combination of solid and perforated waffles is in acoustic isolation. When a 10'-0 x 10'-0 space is partitioned, 4 - 5'-0 x 5'-0 waffles are enclosed. Since only every other waffle is perforated, in a 10'-0 x 10'-0 space there would be four perforations to be sealed instead of eight.

The columns consist of 4 - 2'-6" x 2'-6" 'L' shaped members. They form an exploded cross. The exterior dimensions of the columns are 10'-0 x 10'-0. The space they enclose is used as a mechanical room to bring up the vertical services. Each column services a 50'-0 x 50'-0 area on 4 floors.

## CONSTRUCTION METHOD

Each 100'-0 x 100'-0 unit is structurally self sufficient. The column sections are precast. Four floor sections, or crosses, are cast into the top of the column. The columns are first erected, then the floor units are assembled on scaffolding around the columns. All of the units and the columns are strung together on post tensioning wires. The wires are secured on one side and stressed from the other. Then liquid grout is injected into the post stressing tubes with pressure to seal the channel and the wires. Then the scaffolding is moved on to the next unit and the same operation repeated.

Each unit is structurally isolated. The floor and columns are joined in the post stressing process. The resulting waffles are blocked at the top with 3" tectum board which also serves as a sound absorbing element. Then a 3" slab is poured over the structure. The slab is poured in 100'-0 x 100'-0 sections following the principle of structural isolation.

The next unit is simply butted against the first one. They are connected with sliding joints. This system of construction provides the greatest ease in lateral expansion. Since the units are cantilevered, there is no need to provide additional support for the existing structure while digging foundations for the expansion. Moreover, there is no need to over design the column footings as a provision for lateral expansion.

The structural units, when combined, form ribs 100'-0 long, 5'-0 deep and 10" wide. These are divided into 5'-0 sections. Every other one of these is

perforated. The area of the hole is  $7.5 \text{ ft}^2$ . The columns connect the ribs along the non perforated section. The size of the hole was determined by shear and by bending moment. Eight of these ribs pass through the columns and direct contact between the ribs and the columns is made at 32 points. This distributes the load and reduces the stress per section of rib. The design of the rib was determined by the most critical condition; that is, the rib receiving the largest share of the load. The effect of the negative moment of the cantilever was not considered in the design of the rib. Thus, the structure would be sound even when any one or more of the cantilevers were removed. The possibility to remove cantilevers would give the units a range of flexibility in assembly and possibility of varied spatial configurations by removal of cantilevered sections.



## CORES AND CIRCULATION

Two types of cores can be designed for this system. They fit in the spaces between the main 60'-0 spans. One is 40'-0 x 40'-0 or 35'-0 x 35'-0 clear. And the other is 40'-0 x 60'-0 or 35'-0 x 55'-0 clear. It is possible to design various core types for each of these spaces. These are designed to service 180, 240 and 300 persons. Each core can service a 4-unit or 200' x 200' area. The maximum distance from any door to the fire stairs would be 150'-0.

Each core may combine all the service and circulation elements. Or they can be designed as vertical circulation and service cores. The former contains passenger elevators, large stairs, telephones and janitors' closets while the latter would contain service elevator, fire stairs, telephones, men's and women's toilet rooms.

Internal circulation can follow varied patterns. In the building developed to illustrate the use of this system, the main corridors surround and join the cores. A secondary, peripheral corridor surrounds the building and services the small peripheral office or classroom spaces. The corridor is 10'-0 wide except when the columns are exposed. If they project, the space becomes 7'-6". If they are indented, the space widens and is used for drinking fountains and fire hose. In both cases, access to the interior of the column is off the corridor. The main corridor is 15' wide around the cores.

## THE MECHANICAL SYSTEM

The mechanical system is distributed. The main vertical supply lines are in the columns and they feed into the structural floor. Each column contains a complete set of services. They service a 50'-0 x 50'-0 area on four floors.

Supply and return air, gas, hot and cold water, vacuum, steam, sewer, exhaust air, and high power electric bus wire are distributed. These services are considered to be general requirements of laboratories. Additional supplies, such as oxygen and other gases, are more specialized and will be brought in in tubes. The electrical and telephone conduits are installed within the floor slab. Conduits are extended to service the ceiling lamps below. The conduits service every 5'-0 x 5'-0 module. Telephone and electrical control panels are installed in each column.

Air at an even temperature is supplied. Rooms at the periphery receive individual re-heat or cool units to recondition the air at will. It is possible to install individual conditioning mechanisms for each 100'-0 x 100'-0 unit and vary the supply. Or, re-heat or cool units may be installed within the structural floor to recondition the supply if necessary.

High speed supply air at the rate of  $1.2 \text{ ft}^2$  per  $1000 \text{ ft}^2$  floor area and low speed return air at the rate of  $2 \text{ ft}^2/1000 \text{ ft}^2$  floor area are used. These standards require  $32 \text{ ft}^2$  of space for vertical ducts to service four floors. The space available in the columns is  $44.7 \text{ ft}^2$ . Thus both pipes and ducts can be transmitted through the columns. The vertical ducts diminish in size from floor to floor. This further

frees the space and creates additional working room within the columns.

The area of the largest horizontal duct is  $7.1 \text{ ft}^2$  or  $3'-7" \times 2'-0$ . This breaks down into secondary ducts which in turn supply the distributor ducts  $18" \times 9"$  in size. Supply and return distributor ducts are placed next to one another and occupy the same module. Every other module is provided with air. Air is provided  $10'-0$  on center. However, each duct is capable to supply and return  $15'-0$  on center space. This increases the range of varied room arrangements with balanced air supply and return. The outlets may be regulated to let through specific volumes of air.

4", 6", and 12" pipes are assumed for the vertical mains. A 4"-6" space is allowed around each pipe for ease in making new connections. Pipes through the structure are  $1 \frac{1}{2}"$ , 2", and 4" in diameter. Again, they are surrounded with a 4"-6" space. The pipes run in every other module in a direction perpendicular to that of the air ducts. This system of distribution minimizes the conflict which might result from the occurrence of duct and pipe outlets in the same module. A  $10'-0 \times 10'-0$  space can be completely serviced with air and pipes and each outlet located in a separate module. The pipes are so distributed that they need not cross one another. Only elbow and T connections are used.

$2'-0 \times 2'-0$  lamps with 3-4 tubes are installed in each module. The tubes may be 20 or 40 watts. This gives a range of illumination 48-96 foot candles/each module or  $25 \text{ ft}^2$  area.

Perforating only every other module makes acoustic isolation easier. As

already explained, it increases the amount of solid structure for placing partitions and halves the number of holes to be sealed. Sealing will be by means of metal lath and plaster panels. Tectum board used to seal the waffles also provides sound absorption.

## PARTITIONING

The spaces may be partitioned at any 5'-0 module. The location and size of the column places some constraints upon partitioning into small spaces. However, a 10'-0 x 10'-0 interruption does not constitute a serious barrier. They act as additional rooms. Large spaces may be serviced with air directly from the columns with no need to extend pipes through the structure. Again, laboratories may be so located that each one may have one column and its own set of supplies. Or, up to four laboratories may share a column and use the services without disturbing each other.

## CONCLUSIONS

The system developed in this thesis lends itself to the formation of large buildings or complexes of buildings. The large spans, heavy structure, and ability to bring a maximum number of services to every 10'-0 x 10'-0 space are especially suited to academic, industrial, and research buildings and possibly to hospitals as well.

The system is readily applicable to the formation of a series of buildings as well as to large individual buildings. It is possible to build each unit independently so that one may be 4 stories, another 6, 8, and so on. Since the mechanical space within the columns services 4 floors, every fourth floor a new mechanical room would be needed. Or, in an 8-story building, for example, there may be 4 floors below and 4 above the mechanical room. Thus, various building heights may be achieved. As already discussed, the system is also well suited to lateral expansion with respect to construction.

The mechanical and structural systems are closely integrated in the proposed building unit. The vertical service lines and structural supports occur at the same place. The space necessary for transmission of vertical supplies and the material needed to insulate and conceal these shafts have been incorporated into the structure. The horizontal lines of distribution and the structural floors also have been fused into one space. And the connections between structural elements and between mechanical elements occur in the same area. The module of distribution of services, the spatial module, and the structural module are closely related. All modules

are multiples of the 5'-0 x 5'-0 structural module.

The distributed mechanical system reduces the dimensions of individual vertical chase space, and since the service area of each chase is small, the sizes of horizontal ducts also are smaller than they would have been in a concentrated system of distribution. Moreover, the distributed vertical supplies allow for a more flexible and freer system of servicing a space while causing least disturbance to other spaces. Possible locations from which new services may be extended are numerous. Thus it is possible to plan the extension of services so as to cause least disturbance to already established spaces. These advantages of the distributed system must be weighed against the disadvantage of having a 10'-0 x 10'-0 obstacle every 40'-0 and 60'-0 on center. We believe that the stated advantages offset this shortcoming and that it is possible to subdivide the spaces so as to minimize this disadvantage.

While studying the system at the final phase of selecting standard size equipment, the 5'-0 x 5'-0 module proved to be too small. The 4'-2" x 4'-2" clear space in each waffle is too small to fit in a standard 4'-0 square lamp and an air or pipe outlet at the same time. Unless one agrees to use a rectangular lamp, which may not be visually suitable for use in a square opening, one has to use the 2'-0 lamps. And these are not only less efficient, but are also too small with respect to the scale of the surrounding structure. Another possibility is to seal the opening with the lamp. While this may be a possibility in some spaces, in others it would make it impossible to reach the pipes or ducts behind the lamp.

One shortcoming of the system is its size. The smallest single building that can be developed with this system and have possibilities of variations in interior spaces is 300'-0 x 400'-0. Another reason for this shortcoming is the discontinuity of the structure. While this allows for ease in lateral expansion, it limits the designer. The space can be varied by either removing whole units, skipping floors, or cutting either one or more of the cantilevers. The design of the ribs to withstand maximum loading conditions makes it possible to cut any one of the cantilevers. In such a case, the ribs which are directly connected to the columns act as beams. The dimensions of spaces which can be varied, thus, are 40'0 x 40'-0, 40' x 60', and 100'-0 x 100'-0. It is not possible to hollow out the 60'-0 x 60'-0 spaces because this part of the structure supports the cantilevered sections. Also, since the cores fit in the hollows left by removing the cantilevers, varying the heights of the spaces in the units becomes functionally unfeasible. For, these spaces are needed to provide landing space in front of the stairs and elevators.

The building developed to illustrate the application of the system demonstrates this limitation of the building unit. The building is 600'-0 x 600'-0 and has 4 floors above ground and a basement and mechanical floor below. The cooling towers are on the roof and fresh air is brought in to the mechanical room by means of a tunnel.

The structure is composed of 36 building units. Each unit is so planned as to have a maximum of 4 floors above the mechanical room. The cores are wedged

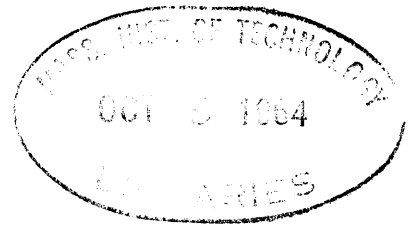


into the 40'-0 x 60'-0 spaces between the 60'-0 x 60'-0 main spans. Two types of cores are used: a vertical circulation core and a service core. There are 4 of each type or a total of 8 cores to service the building. Since, as already explained, each core limits the spatial flexibility of 2 building units, the cores were concentrated to minimize the number of such fixed units. The cores were arranged into 4 groups each consisting of a service and a vertical circulation core placed on either side of a lobby space. Then, these groups were arranged in two bands on either side of the building. Thus twelve building units are fixed and the remaining 24 are variable, or 30% of the building is fixed. This condition imposes many constraints upon the design of the interior spaces.

The solution proposed concentrates the spatial variations in the 8 central building units while the remaining units form a 4-story rim about the central portion. The building is entered through low and partially enclosed spaces. These lead to two-story lobby and exhibit spaces on either side of the building. These spaces are joined by means of an open, central court. The exhibit spaces are adjoined at either end by the elevator lobbies. Thus, the hierarchy of spaces take the following pattern: the central court joins the two main lobby and exhibit spaces. Each such space joins two elevator lobbies. And each elevator lobby joins two cores. The elevator lobbies are repeated at each floor and visual connections with the central court are provided on each level. By providing long range views through and across the building, the design attempts to create an awareness of the volume which the structure defines.

The exterior treatment of the building was determined by the requirements for lateral expansion and by the assumed distribution of uses within the building. The exterior walls should be composed of removable panels in order to allow for lateral expansion. This eliminates the possibility of using bearing walls surrounding the building or heavy pre-cast or cast in place window units. Instead, pre-cast mullions and sills and glass panels are used as the building envelope. Balcony rails are pre-cast sections mounted onto the fascias. Thus, the exterior is composed of easily removable and re-usable pre-cast elements. Varied uses were assigned to each floor. The first floor is the most public and contains lobbies, exhibit spaces, large lecture halls and so on. The second floor contains libraries, administrative offices and large class rooms. The third floor consists of class rooms, teaching laboratories, and offices. And the fourth floor is the most private, containing specialized laboratories and offices. The elevation study attempts to express this progression from the more public to the more private uses.

In summary, this study develops a structurally and mechanically integrated and self-sufficient building unit. It is applicable to large buildings such as schools and research and industrial buildings. It allows maximum flexibility in the distribution of services and in lateral expansion. The main shortcoming of the system is that it cannot be readily used to form smaller isolated structures. However, the principles of structural isolation for lateral expansion, and the use of a distributed mechanical system for maximum flexibility in and accessibility to services is still valid. They can be applied to develop smaller units which hopefully would allow for a wider range of spatial configurations.



A RESEARCH AND DEVELOPMENT BUILDING  
FOR SCIENCE AND TECHNOLOGY  
SUITABLE FOR BOTH  
ACADEMIC AND NON-ACADEMIC USE

by

CHARLES BURTON HOOK

B. Arch., University of Illinois

(1963)

SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE  
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at the

MASSACHUSETTS INSTITUTE OF  
TECHNOLOGY

June, 1964

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Lawrence B. Anderson  
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June, 1964

Pietro Belluschi, Dean  
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Cambridge 39, Massachusetts

Dear Dean Belluschi,

In partial fulfillment for the degree of Master of Architecture  
I hereby submit this thesis entitled, "A Research and Development Building  
for Science and Technology Suitable for Both Academic and Non-Academic  
Use."

Respectfully,

Charles B. Hook

## ABSTRACT

This thesis is concerned with the development and use of technological and functional criteria as a basis for architectural design. Hopefully, this method will produce a building expression of enduring quality and usefulness based on a totally integrated system of construction free from the compromising influences of current fashion and individual mannerism.

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Structures - Mrs. Deborah Forsman

Mechanical - Mr. Sital Daryanani

Design - Professor Eduardo Catalano, Thesis Supervisor

## I. INTRODUCTION

The Twentieth Century heralded in a new era of vast social changes and scientific and technological advancements to which the latter decades of the Century promise to give added impetus. Such rapid changes have created a complex, and often chaotic, world society which presents man with new problems added to many age old problems. Attempting to solve these problems man tries to regulate and discipline, diversify and simplify life, seeking order out of confusion, striving toward a Utopia.

Architecture too is feeling the grip of our complex society and consequently is in a period of change. To fight confusion in architecture the beginning of an architectural science based upon construction and systematic design may possibly replace temporary formalism and individual mannerisms in the future of architecture. A science or building system of this nature would be governed by growth, transformation/change, flexibility, identification, integration/segregation, minimum work, economy of means, integrity, and construction. It is hoped that with such a system of building, architectural problems, and thus in turn some of the problems wrought by the complexity of our society, might somehow be alleviated.



## II. PROGRAM

A general program reflecting the overall nature and basic requirements for a research and development building, facilitating academic and non-academic use, is set forth in the "Aim of Thesis" given in the preceeding general discussion. Since flexibility and possible change govern practically all of the design criteria, no specific requirements concerning functional and spatial needs are given. The many activities possible in a building of this type include: offices, lounges, classrooms, libraries, lecture halls, auditoria, exhibition areas, museums, meeting rooms, workshops, drafting rooms, seminar rooms, laboratories, and storage spaces, to name only a few of the more important ones.

The following are specific qualifications set forth at the beginning of the study. The gross floor area for the entire structure was set to be between one million and one-and-one-half million square feet. A minimum gross floor area per floor of 40,000 square feet determines the maximum number of floors. A ten foot clear floor to ceiling height was considered adequate for all single-story functions.

### III. BUILDING CONCEPT

A research and development building built within today's advanced technology heralds a new scale in architecture. Structural innovations and advancements provide greater spans than were previously possible under similar conditions. Flexibility and growth requirements demand large uninterrupted areas. As a result, a new scale in architecture for this type of building is generated.

The large building created by this new scale in architecture creates many new problems for the architect. The building is comparable to a city with its many functions, its complex circulation patterns, and its need for a hierarchy of all elements. Activities must be related to more important areas, and a climax for all systems must be reached. Orientation problems in a large building such as this can be partially solved with large voids and open areas. These voids establish a hierarchy of life within the building and also permit light to become a part of the interior spaces. It is for a building with such a physical character that the various systems used throughout the building were designed.

#### IV. STRUCTURE

In the general discussion on systems which preceeded this thesis, it was noted that systems dealing with structures were very important. During the study and design of the Research and Development Building, the above fact concerning the importance of the structural system became evident. It was found that all of the other systems in the building will depend upon the type and development of the structural system.

With such importance placed upon the structural system, much time was spent in searching for a structural unit or system which would lend itself most clearly to the integration with the mechanical, acoustical, circulation, and planning systems within the building. A basic unit capable of imposing no limitations to the building was sought. Expansion within and without the building was considered to be of prime importance as a requirement for the basic unit to possibly satisfy. The size and number of the units which made up the overall structural system would govern and set the limitations for the building as a whole. A one way linear system was finally chosen after much study of various possible systems.

A one way system was chosen because of the following advantages. Erection of the basic unit could be done with ease and great speed. Piping and ductwork could easily be placed between the one way elements. The possibility of removing units to form two-story spaces without interrupting the total system is great. And, simple precasting and prestressing techniques can easily be

accomplished. For the basic unit, industry's common "T" section was chosen after a close study of the unit's requirements for utility accessibility, modular sub-divisions, and ease in formworking.

The great number of identical "T" sections naturally led to the precasting and prestressing of this basic unit. In order to minimize the problems of connections and joints always present in precast work, the girders, columns, and all other structural elements will be cast in place. This will also facilitate greater ease in achieving continuity for columns and girders.

The module maintained throughout the building is 4'-8" by 4'-8". This dimension was determined rather arbitrarily, except that it was considered to be the closest spacing of joists while still allowing a standard 4'-0" illumination panel to fit between the joist ribs. The structural bay is 56'-0" (12 modules), by 28'-0" (6 modules).

The structural framing system is simple. The joists are 4'-3" deep and placed on the 4'-8" module. They are supported by 2'-9" deep girders which have a clear span of 23'-10". The difference in depth between girder and joist results when the girder is continually punched to allow passage of mechanical equipment to and from the corridors. The four main corridors running in the long dimension of the building are a result of double girders. Short stub "T" sections, 1'-6" deep, which line up with the main "T" sections, span the corridor. A 3 inch concrete topping is finally placed over the "T" sections making the total structural depth 4'-6".

## V. CORES AND CIRCULATION

The number and arrangement of permanent service cores within the building determine to a great extent the overall circulation system. Originally a system with many cores was studied. The intention was to use the core as a structural column, therefore having no interior columns. Exterior elements as well were to be used to serve the permanent systems of the building. A principle reason for abandoning the system was the lack of large unobstructed floor areas, especially around the building perimeter. Also the exterior service elements took much of the prime window area as well as being an aesthetic troublespot.

In the final solution a system of eight service cores was developed. Of the eight there are two different core types. Each has the same facilities for mechanical and utility requirements as well as required fire stairs. The variation in the two core types lies in different toiletroom facilities and different types of elevators.

The main system of circulation is developed around the eight service cores. Traffic is considered to be the heaviest in the longer dimension of the building, especially around the central voids and activity areas. The widths of the corridors are sized in accordance to this hierarchy. Also all traffic in and out of the cores is from the core sides which allows uninterrupted flow along the major corridors. Secondary and minor circulation patterns will be a result of the spatial arrangement of rooms and partitions.

## VI. MECHANICAL SYSTEMS

The mechanical systems are integrated with the structural, circulation, and core systems in the building. All of the mechanical facilities originate in a mechanical floor, travel vertically through the eight service cores, proceed horizontally along the corridors between the double spaced girders, and finally branch into the joist feeder lines. In order to use as little depth as possible for the ducts in the corridors, the supply and return ducts originate from opposite directions so as one diminishes while the other increases. The sizing of ducts is based upon a rough figure of two square feet of duct area for each supply and return duct for every 1000 square feet of gross floor area served. A low velocity system is used. The necessary depth for ductwork in the corridors is a result of these figures, and thus the structural depth for the entire building is established. For the building's exterior zone a fan coil unit is used for conditioning the air. The facilities for this auxiliary system rise in the large exterior columns.

The requirement of complete planning flexibility-change-and-growth, necessitates a very flexible utility system. For ultimate flexibility there are numerous service lines which must always be available. They include: hot and cold water, tap water, steam, vacuum, compressed air, natural gas, and various drains. A main supply line for each of the above is found in all of the four major corridors. From these main service arteries, secondary feeder lines branch perpendicularly into the "T" sections in every other module alternating with the air

conditioning ducts. There are two points along the joists where openings allow still another perpendicular branch of piping. An exhaust and venting system is also established within the major corridor service "streets."

The signal and electrical systems follow the same paths as do the piping and duct networks. The wire and conduit systems travel from the cores in large bus conduits before being distributed into the joist runways. The illumination pattern in the building is a linear system placed perpendicular to the joists. This establishes a modular regulation in the opposite direction from the one way joists. This also allows much freedom for accessibility to piping and ducts.

The acoustical control from room to room proved to be a major problem for this building. Along the joists, partitions will come to the underside of the "T" sections. From joist to joist, it is hoped that the filler panel will work beneath the ducts, while mesh and plaster was the only solution found for sealing around the pipes.

The primary goal of this building is to provide utmost flexibility for any possible condition. The mechanical and service systems outlined above will provide all facilities to any space with 9'-4" as its smallest dimension.

## VII. CONCLUSIONS

The size and scope of this thesis proved to be overwhelming. All of the study was done with the assumption that an ideal solution was possible. No such solution was found. The unwritten goal of trying to produce something beneficial for the construction and building industries proved to be frustrating when already accepted procedures were found to be better than the newly proposed ideas.

The design of a building of this nature resulted in many compromises. When the mechanical system is to be integrated into the structural system, the structure, somewhere, must be punctured. A compromise in structural clarity between girder and joist depths and spans results. Also, the greater than necessary overall structural depth is a compromise generated by the type of mechanical air distribution used. The development was further hindered by the lack of personal experience in the technical fields being studied.

The solution presented in written and graphic form may be considered to be less than an ideal solution for the problem. But the process of study and the overall knowledge obtained through the development and work on the project resulted in success.





AN ACADEMIC / RESEARCH AND DEVELOPMENT  
BUILDING FOR SCIENCE AND TECHNOLOGY

by

GEORGE NORMAN HOOVER

B. Arch., University of Oklahoma

(1957)

SUBMITTED IN PARTIAL FULFILLMENT

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June, 1964

Pietro Belluschi, Dean  
School of Architecture and Planning  
Massachusetts Institute of Technology  
Cambridge 39, Massachusetts

Dear Dean Belluschi,

In partial fulfillment for the degree of Master of Architecture  
I hereby submit this thesis entitled, "An Academic/Research and Development Building for Science and Technology."

Respectfully,

G. Norman Hoover

## ABSTRACT

This thesis is presented as an Academic/Research and Development Building for Science and Technology in which the primary consideration was the design of an integrated mechanical-structural system of construction that could produce a building providing maximum flexibility in terms of space, circulation, services and capability of future change. A system that would then manifest itself as something more--a meaningful architectural expression.

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Structures – Mrs. Deborah Forsman

Mr. William LeMessurier

Mechanical – Mr. Sital Daryanani

Design – Professor Eduardo Catalano  
Thesis Supervisor

## I. DESIGN CONCEPT

A. PROGRAM: With the primary objective the development of an integrated mechanical-structural system of construction providing maximum flexibility and capability of future change, the following programmatic requirements were established:

1. A total gross floor area of 1,000,000 to 1,500,000 square feet.
2. A minimum area/floor of 40,000 square feet.
3. Floor to floor heights can vary but the ceiling height should be constant on each level.
4. Live load of 125 psf throughout.
5. Toilets, exit and elevator capacities calculated on 150 square feet of gross area/person.
6. Maximum distance to fire exits - 150 feet.
7. Planning module based on illumination requirements and minimum widths of rooms and corridors.
8. Local structural demountability for vertical expansion.
9. Accessibility of all utilities mandatory.
10. Noise control from room to room necessary.
11. Sun control as part of the unified solution.

In addition to these requirements the building would have to provide space suitable for all the following activities:

1. Laboratories
  - a. Instructional
  - b. Research
  - c. Testing

2. Workshops
3. Classrooms
4. Seminar Rooms
5. Small Auditoriums
6. Studios
7. Drafting Rooms
8. Departmental Libraries
9. Administrative/Staff Areas
10. Faculty/Assistants Offices
11. Lounges
12. Storage
13. Maintenance
14. Mechanical Equipment

## B. BUILDING EXPRESSION

The resultant design is a building of five floors arranged in a "pin-wheel" plan of four 200' x 400' linear quadrants forming a hollow square approximately 600 feet on each side. Each of the quadrants is composed of eighteen 66'-6" square bays, has a floor area of about 75,000 square feet, and is served by two cores, one in the center and one on the periphery. A typical floor has an average area of some 300,000 square feet. The upper three (typical) floors have a 14'-9" floor to floor height and are served mechanically from a penthouse above. The ground floor, serving as the main entrance level, has a greater height of 22'-4".

The basement floor, opening onto a 200 foot square central courtyard, has the same height as the typical floors--14'-9". A mechanical sub-basement serves the lower two floors.

There are two core types--a major central core serving 12 bays and a minor peripheral core serving 6 bays. The four central cores fit within a typical structural bay and are not required to be load-bearing construction. They contain the major circulation stairs, elevators, toilets, janitors' closets and mechanical chase space. The four peripheral cores are contained within a 22 foot cantilever of a typical bay. They contain the secondary fire stairs, service elevators and additional mechanical chases.

### C. INTENT

The design represents an attempt to establish a space-determining system of construction that can create architecture, but not necessarily in the classical form of a building as a complete (and therefore, completed) object. The aim is a humanistic expression rather than the monumental, where human activity is the measure of scale. A building of this size, a million and a half square feet, becomes a small city inhabited by 10,000 people--a minor urban complex within itself which should provide all the desirable qualities of changing scale, centers of life and areas of privacy, and a sequence of activities and climaxes that enhance rather than negate experience. It will also act as the major focal point of an academic complex which will, in turn, interact directly with the greater urban environment



and will be required to respond accordingly to changing demands and conditions for many decades. Realizing this, it seems important to at least make an attempt to create a more meaningful, dynamic thing, not so irrevocably complete within itself, that can accept modification and growth as a natural condition and as a continuing design expression--this will be a more complete and total concept of flexibility.

## II. STRUCTURE

### A. Structural Systems

The building is formed by a combination of basic structural components based on a long-span, structural bay designed to give the maximum amount of unobstructed floor area that can be practically furnished with mechanical services. The typical bay is a square, two-way, pan-construction slab with continuous girders at the perimeter spanning 60'-2" between columns. Each structural bay is separated from the next one by one 6'-4" module--with the resultant unobstructed area used for distribution of the mechanical services. The overall bay is then 66'-6" from center to center. The basic planning module, a 9'-6" square, is divided into a 6'-4" and a 3'-2" structural sub-module with a structural depth of 4'-6 1/2" and a 2 1/2" finishing slab, giving an overall depth of construction of 4'-9". This with a typical floor to bottom of construction height of 10'-0" gives a typical floor to floor height of 14'-9".

The depth of construction is based on the span and the maximum size of perforations through the structural members required for passage of the mechanical services. Live load is calculated at 125 pounds throughout the building. Light weight, 4000 psc concrete has been calculated for all typical construction in order to reduce the dead load. The relatively deep construction of 4'-9" allows the use of conventional reinforcing throughout. Girders are

typically continuous between bays, however, continuity is not absolutely necessary at the periphery except when a floor is cantilevered beyond the last line of columns. The fact that continuity is not always necessary allows considerable variation in the spatial qualities of the building as bays can be left out or cantilevered where desired. It is also possible to leave out, or make demountable, the center modules within any given bay to allow local vertical expansion.

The structural separation of the bays results in a group of four columns at intersections. The columns are structurally independent but are connected with diaphragms to obtain greater rigidity. The resultant space--a typical 6'-4" module--is used for a mechanical service chase.

#### B. Construction Methods

The building is designed to be built totally in cast-in-place concrete using conventional reinforcing. Forming of the structural slab will be with custom-designed metal or reinforced fiberglass pans. Exterior surfaces will be formed with a narrow board form using the slight texture as a final finish. Non-structural exterior walls will be either pre-cast concrete panels or glazing in metal framing--both designed for possible removal when major modifications are necessary in the future. Ground plane surfaces--terraces, lobby areas, and exterior courts will utilize post-tensioning in the structural slab over occupied spaces for water-proofing with a textured, pre-cast paving unit applied for a paving surface pattern.

### III. MECHANICAL SYSTEMS

The primary aim in the design was to develop an integrated framework of structure and chases that would permit the use of several different types of mechanical systems depending upon the demands of the particular space. The design premise was based on a minimum planning module of 9'-6" square, the smallest room that could require the maximum mechanical services of air (supply, return and/or exhaust), lighting, plumbing, power, communications (telephone, signal or closed circuit t.v.) and acoustical control. The source of all these services, except the last, would be one of the mechanical rooms--either the penthouse serving the upper three floors or the mechanical sub-basement serving the ground and basement floors. The typical services and distribution would be planned as follows; however, the total system does offer the space and flexibility to introduce other, more specialized, services when the situation demands.

#### A. Air

Air supply would use a single duct, high-velocity system distributed vertically through the cores from the air-handling machines in the mechanical rooms. Capacity is calculated on 1.2 square feet of duct area for each 1000 square feet of floor area in the building. Horizontal distribution from the cores would be at the center of the structural bay using velocity-reducing chambers containing tempering coils to provide zonal temperature control. Final distribution would be by prefabricated round ducts, 12" in diameter,

in every other module (9'-6" o.c.). At the exterior zone, fan-coil units would be used to recirculate and condition the supply air at the periphery of the building.

Return air would be similarly ducted, or in large spaces, picked up directly by the main horizontal lines running in the space between the double girders. The chase formed by the four columns will be used for the vertical return to the mechanical rooms with the space required calculated at 2 square feet of duct for each 1000 square feet of floor area.

Exhaust air ducts are distributed horizontally at the periphery and at the center line of the building related to the cores for vertical transfer out of the building. It is assumed that the upper floor of the building will be utilized primarily for laboratories where fume hoods can be exhausted directly through the roof.

#### B. Lighting

Typical lighting would utilize standard 2' x 4' fluorescent lighting fixtures hung in pairs in each of the larger, 6'-4" modules below the ducts and other mechanical services. This would provide an illumination level of approximately 50 footcandles in an average room. Where higher levels are required, an additional 2' x 4' unit can be added in the smaller, 3'-2" modules. The system permits the use of almost any type of lighting--incandescent, luminous louvered ceilings, indirect lighting above the ducts, etc. when desired.

### C, Plumbing

Supply, drain and vent piping is distributed vertically from both the cores and the column chases using the space between the girders as the primary horizontal lines. Final distribution to the individual modules used the structural perforations in the larger module along with the return air ducts.

### D. Power

Normal 110 AC power will be distributed from the mechanical floors vertically in the column chases with a breaker panel at each floor serving one typical bay. Horizontal distribution will be by conduit in the floor-topping slab in every other module and by conduit in the ceiling space for the lighting. Special power requirements would be brought from vertical bus-ducts located in each core in the normal piping distribution channels.

### E. Communications

Telephone distribution will be similar to the electrical, using a panel board in the column chase for each bay with distribution in floor conduit. Telephone equipment rooms would be located in the mechanical floors. Special signal and television wiring would be distributed from the cores in conduit as piping.

### F. Acoustical Control

Reverberation control within a space will be accomplished by perforating the metal casing of the prefabricated air ducts utilizing the inherent absorption value of the insulation. The configuration of the exposed structural system will provide excellent sound diffusion. For special requirements, additional absorp-

tion material can be applied to the upper part of the structural "ceiling."

Sound isolation between spaces is the most difficult problem in the use of this type of exposed structural-mechanical system because of the numerous openings required for the passage of the mechanical services. An attempt to minimize the problem has been made in the following manner: first, by perforating the structural system in only one direction except at the center modules of each bay for the passage of supply and exhaust air ducts. Second, by using a continuous, supporting baffle around the supply ducts that seals off the openings in every other module. This leaves then only the openings in the large module in one direction, which can be blocked by ceiling panels above the lighting in small rooms or by special baffles at the periphery of the larger spaces.

#### G. Partitioning of Spaces

Partitioning can be accomplished by almost any method desired. With the ideal of total flexibility in mind, the normal systems, depending upon the type of space, would be exposed concrete block walls, dry-wall partitions of gypsum board on metal studs, or single panels (glass or hardboard) in metal frames. All of these are relatively easy to install and remove and are much less expensive and more durable than the commercial, movable partition systems. Where sound isolation is desired, the use of fiberglass blankets and resilient mounting clips can bring the drywall partitions up to acceptable levels of good privacy. Higher requirements will necessitate the use of heavier, less flexible walls as a solution. In all instances, the exposed webs of the

structural system provide the anchorage point for the top of the partition and impose a predetermined modular order on all space planning.



#### IV. CONCLUSIONS

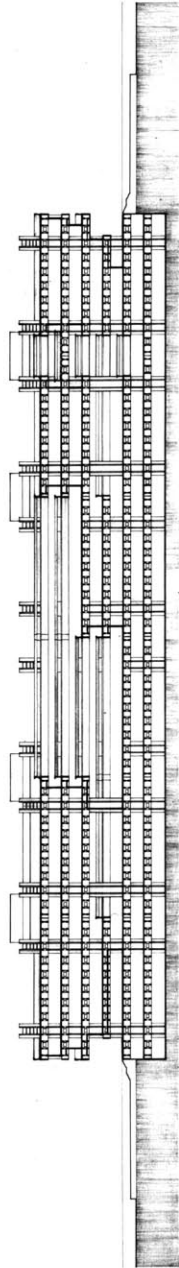
A unified system can be developed that satisfies almost all of the criteria set forth. However, there are inherent contradictions that require some compromises to be made in achieving maximum flexibility. Ideally, the mechanical services should be able to distribute in any direction on the shortest line from point to point, but in order to achieve a needed sense of architectural organization and control of planning, the use of the exposed structural system regularizes the paths of the services and forces them to move laterally in right angle turns--to the point of having to double back on themselves in some instances. The need for maximum unrestricted areas for the distribution of services is also in conflict with the structural requirement for solidity at many points and causes the secondary problem of being able to effect proper sound isolation. It would then seem that there is no perfect solution to the total problem in a building of this complexity.

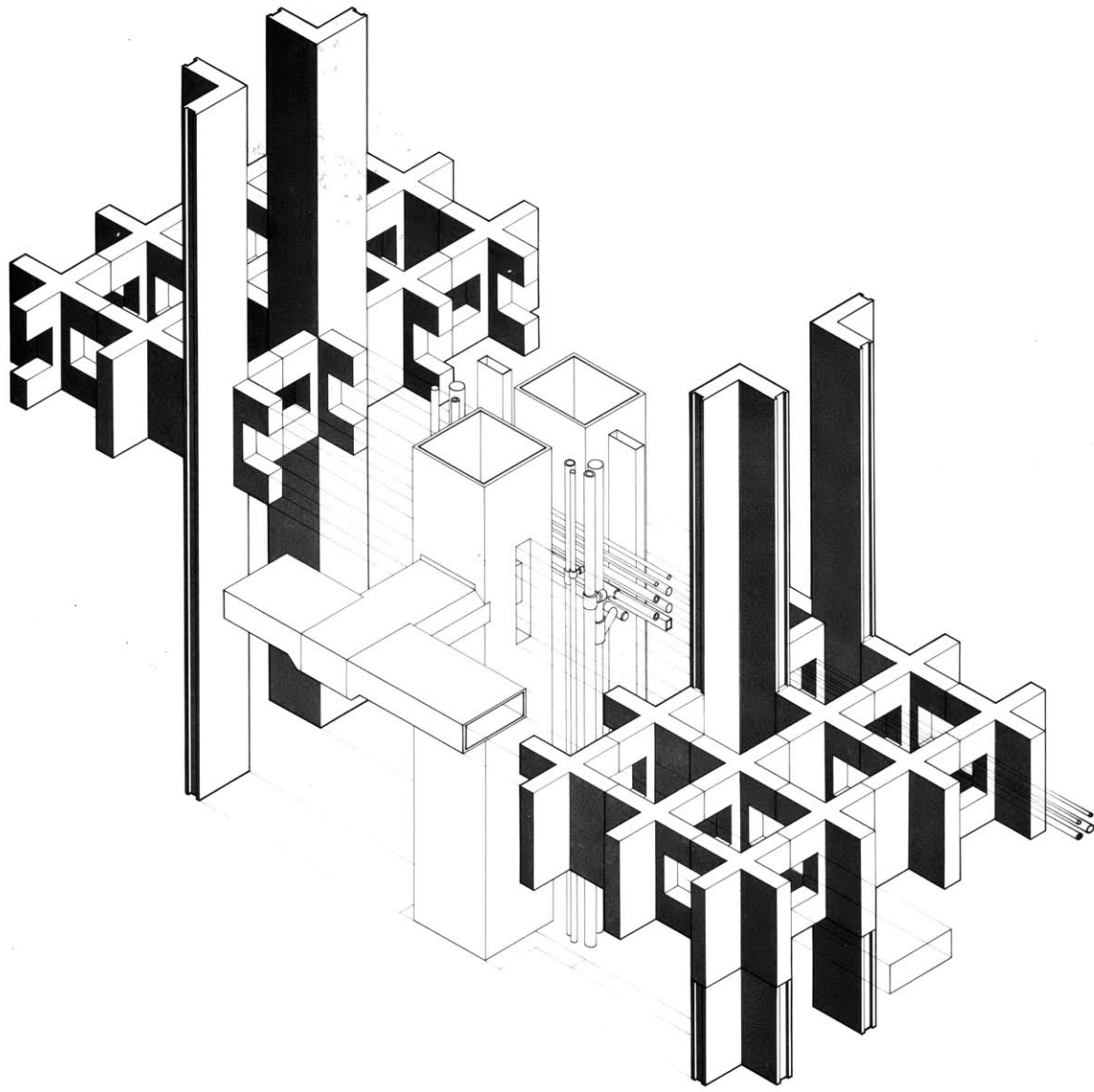
The attempt to have a generally distributed system by integrating the services with the structural supports also has a built-in contradiction as it demands that both the structure (mass) and the service space (void) maximize at the same point. To meet both requirements these points quickly outgrow the sense of being a column and become instead distributed mechanical chases and as such are impeding elements, contrary to the desire for unobstructed floor space. The other alternative, of supplying all the services from the cores, generally requires some very large horizontal chases that cannot be handled in the normal structural module and are then run above predetermined corridor spaces. In this solution the attempt was made to use both

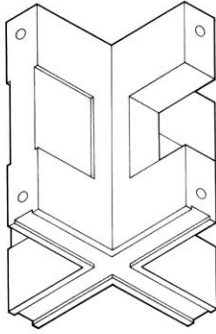
the normal area created by the column groups and the larger spaces available in the cores, thus allowing the structural module to remain constant throughout the building. Circulation space is not fixed to any given position, although the major corridors will certainly fall into certain logical patterns related to the cores.

Finally, the attempt to approach the design of a very large building as a complex of many elements that can express their special functions when necessary seems to be a legitimate one, particularly if it can be accomplished without distorting the framework of an integrated system. In this solution, where no definitive program of space planning has been set forth, the variations in plan, elevation, and section are arbitrary--used only as an attempt to indicate potentialities of the system.

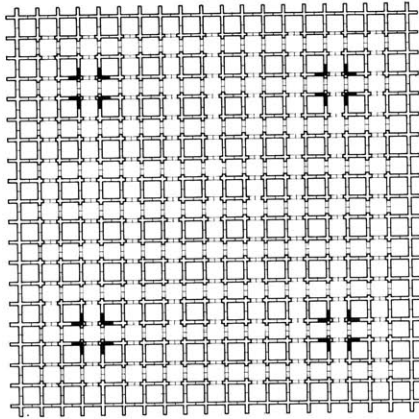
The advantages of the "pin-wheel" plan as a complete system offering, at the same time, the possibility of expansion or extension of certain areas was not developed to any significant degree--nor was the integration of ground plane elements such as larger auditoriums, theaters, libraries, etc. into the building framework to serve as linking elements to the total academic complex. It would seem that both of these approaches are worthy of further investigation in the attempt to find a more complete flexibility and integration on the larger scale of total planning.



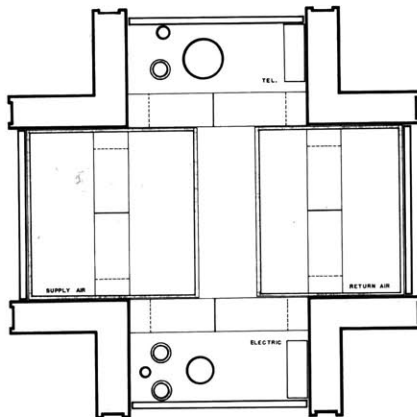




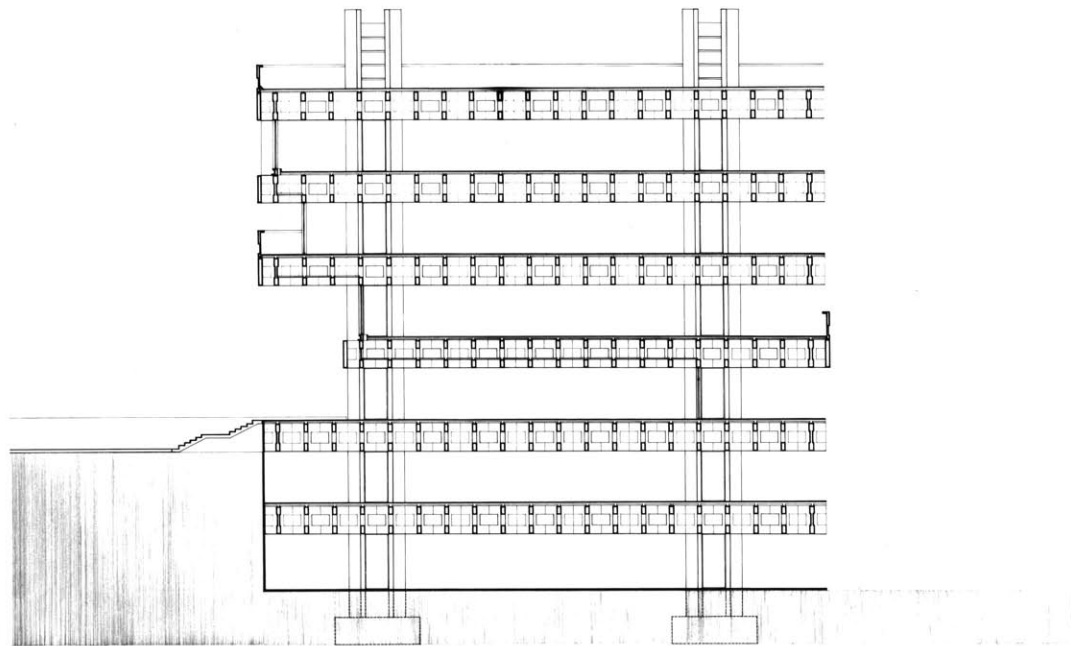
STRUCTURAL FLOOR UNIT  
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HORIZONTAL SECTION THROUGH  
STRUCTURAL FLOOR  
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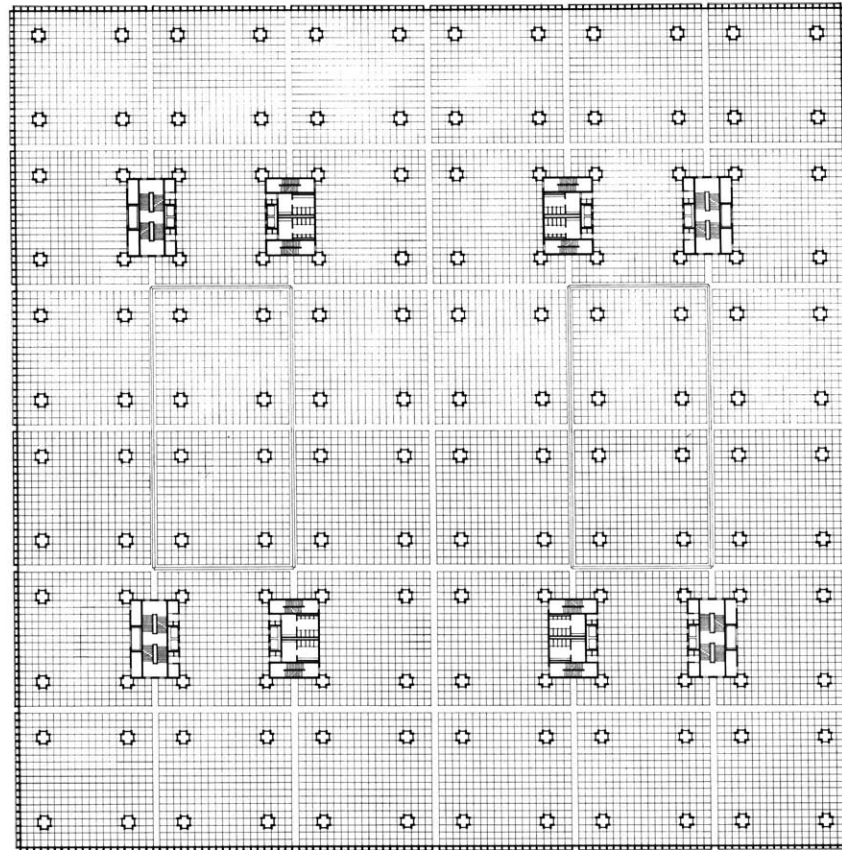


TYPICAL COLUMN PLAN  
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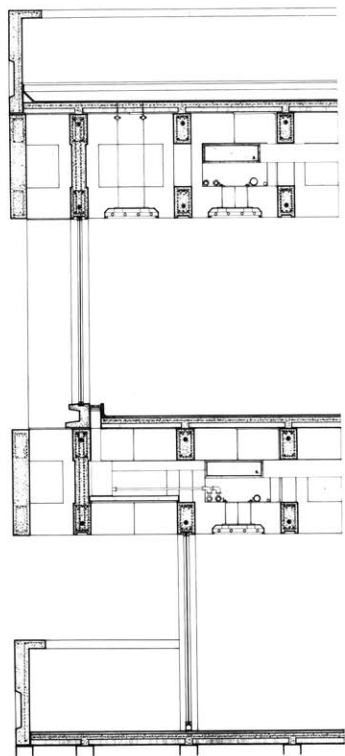


SECTION THROUGH TYPICAL BUILDING UNIT

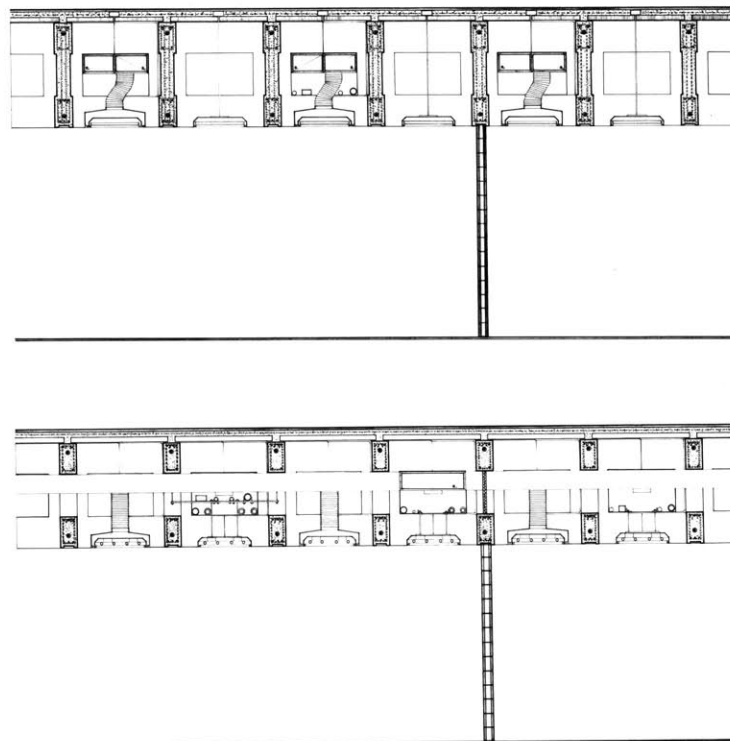
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TYPICAL FLOOR PLAN

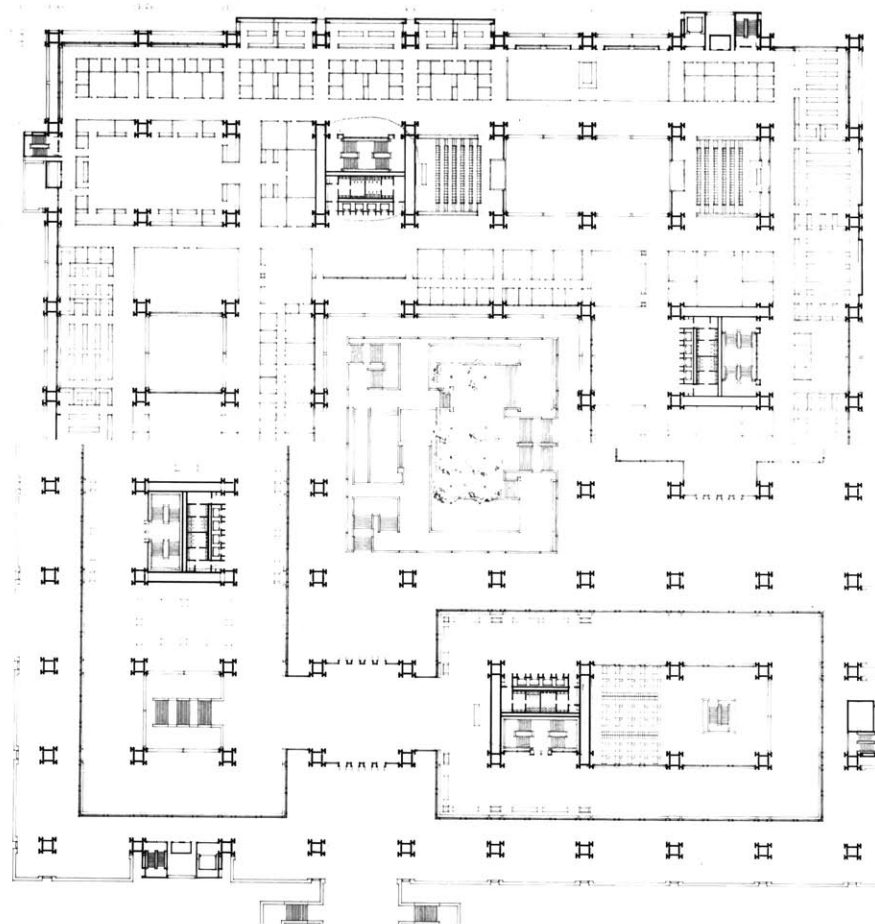


TYPICAL WALL AND FLOOR SECTIONS



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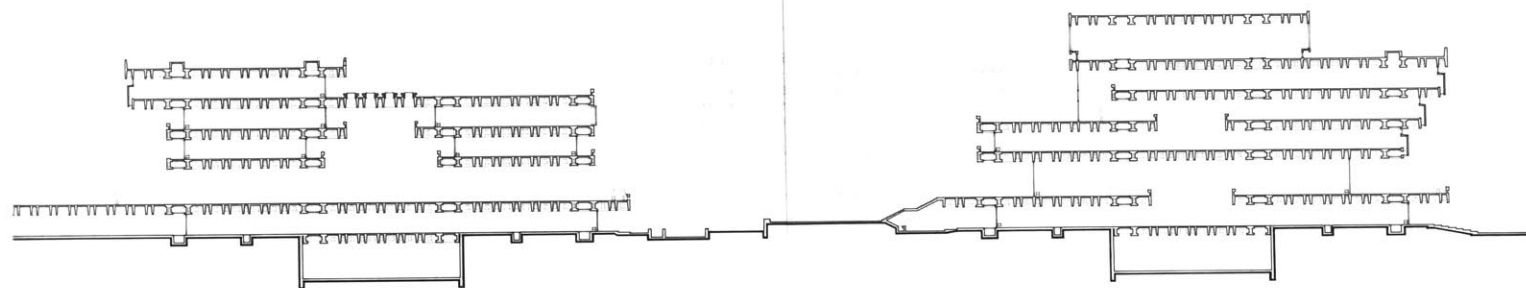


TYPICAL FLOOR  
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GROUND FLOOR  
0 10 20 30

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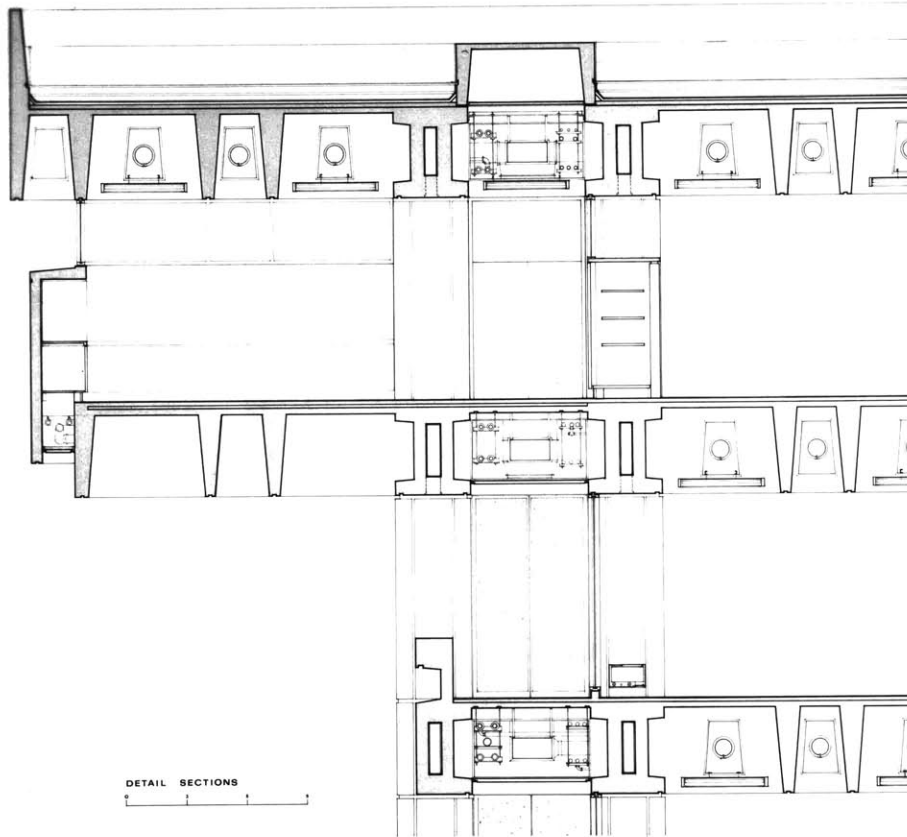
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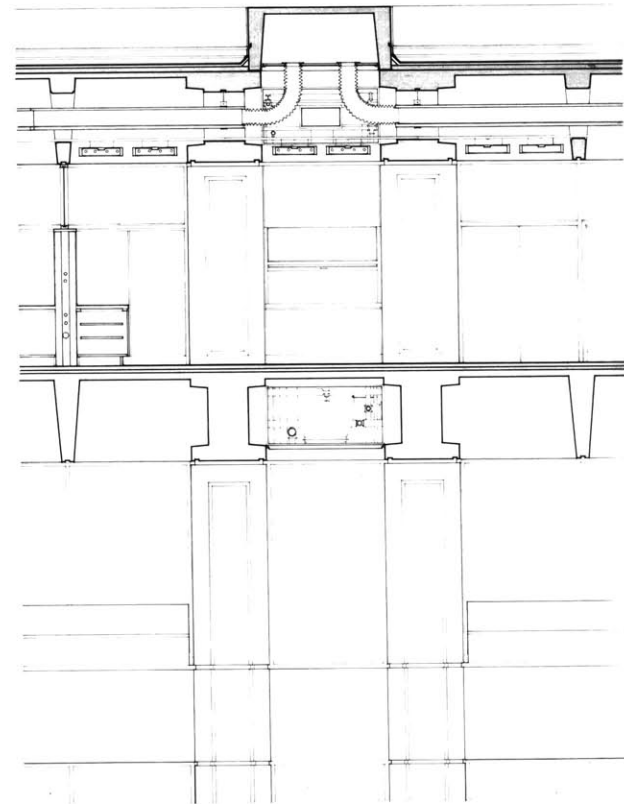
SECTION  
1" = 10'

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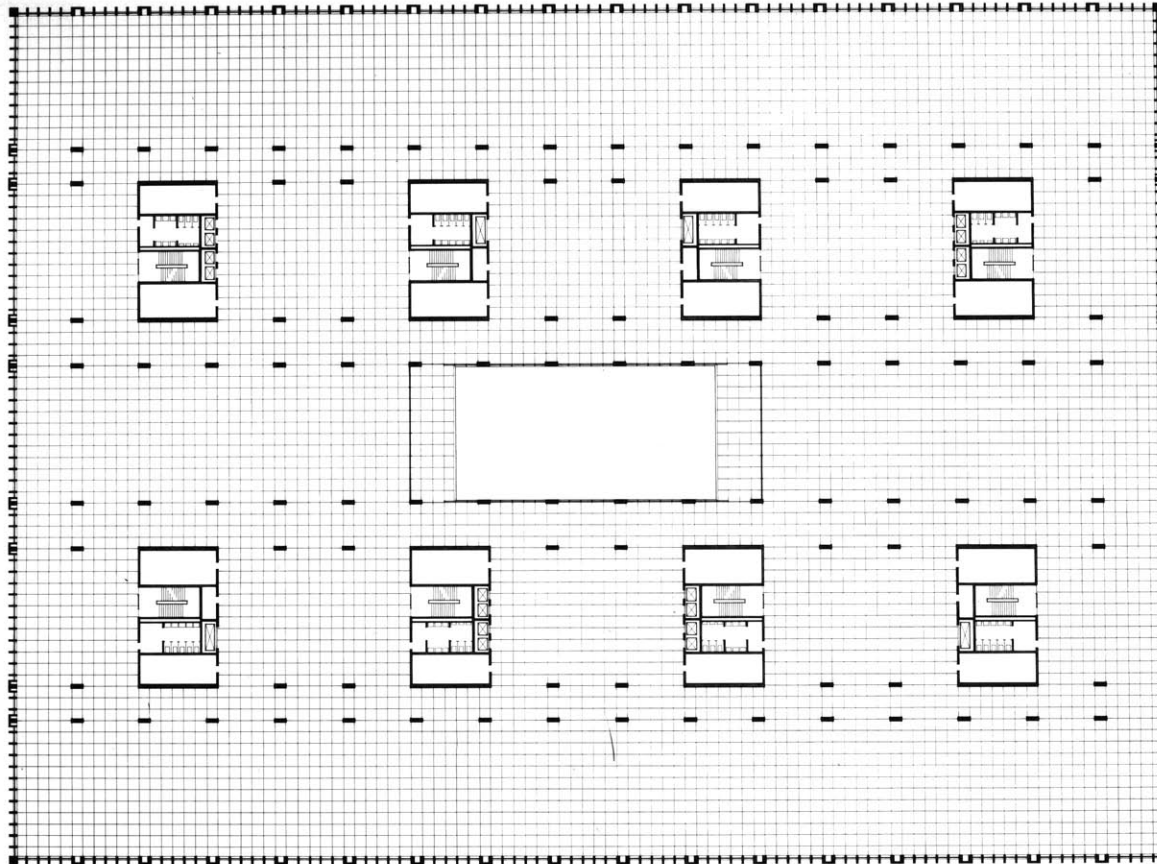


DETAIL SECTIONS  
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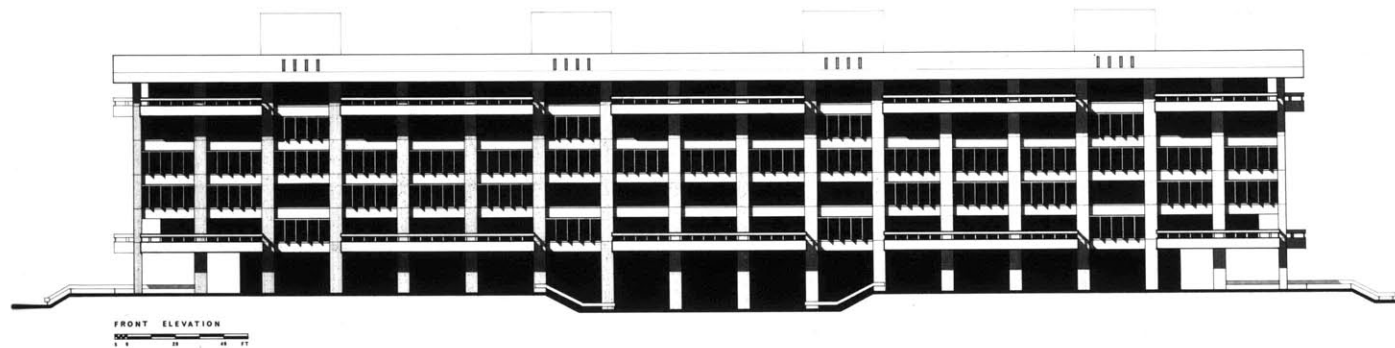
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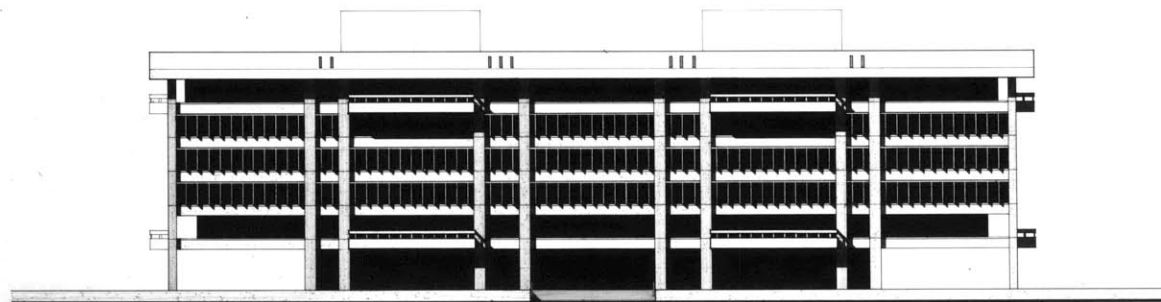


SECOND FLOOR PLAN  
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

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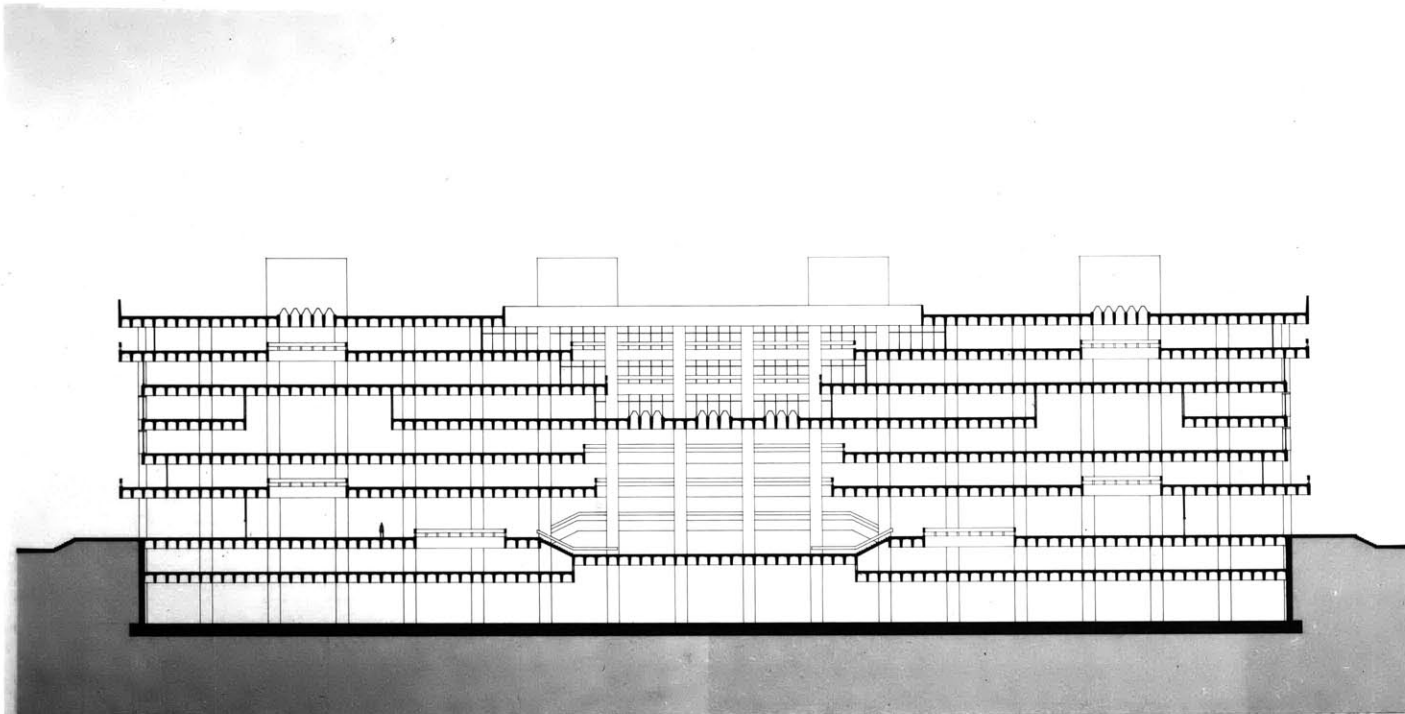


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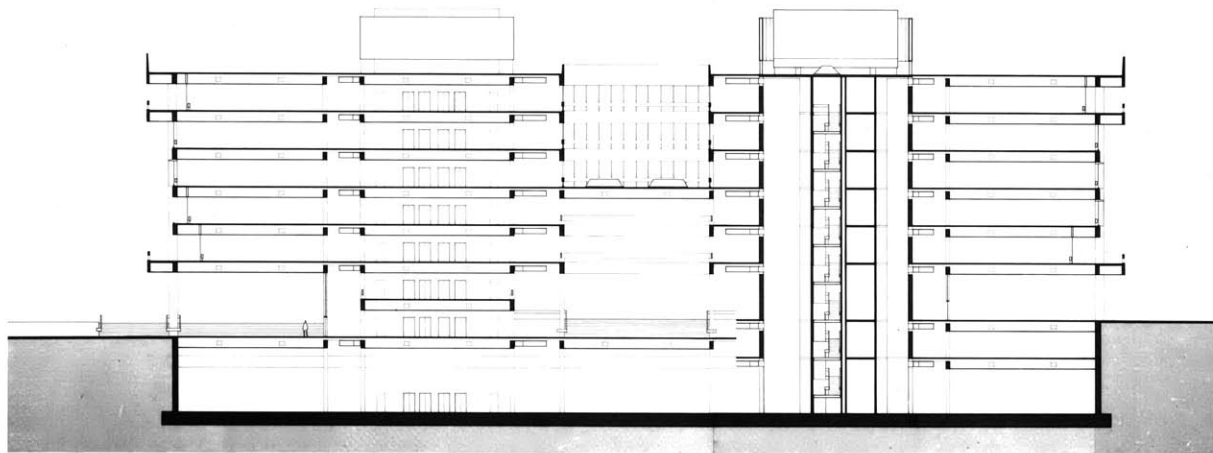
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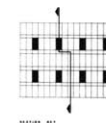


LONGITUDINAL SECTION  
 0 10 20 30 40 50 60

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TRANSVERSE SECTION



PLAN

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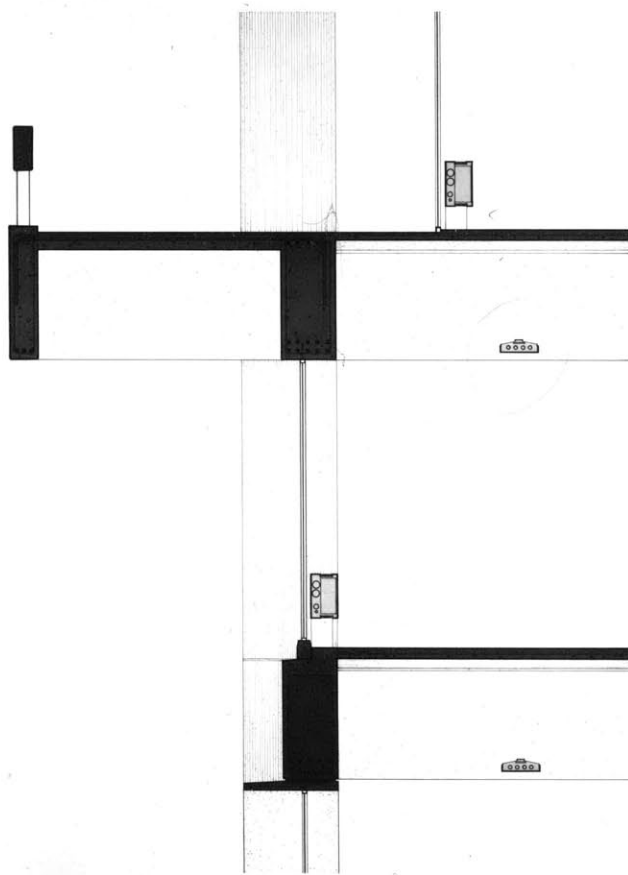


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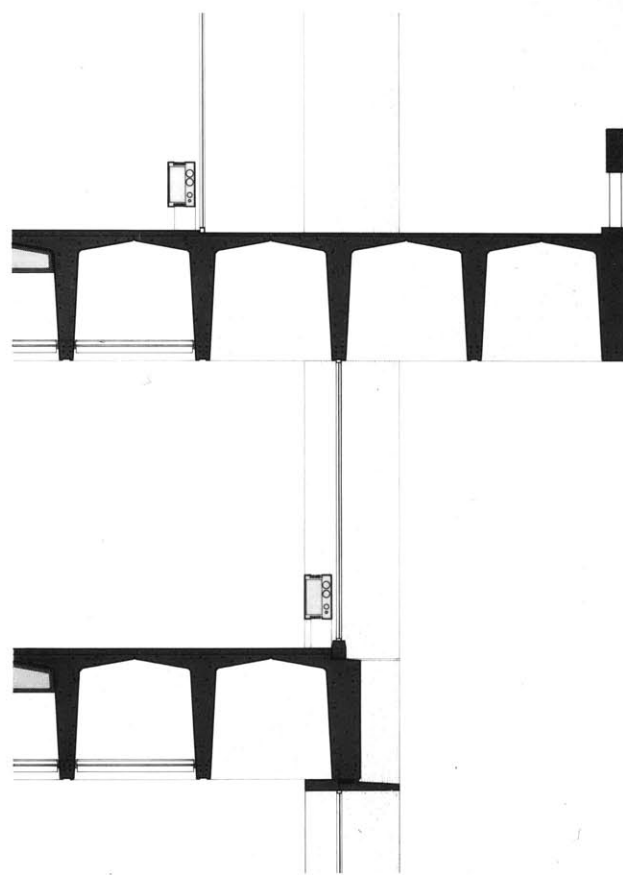
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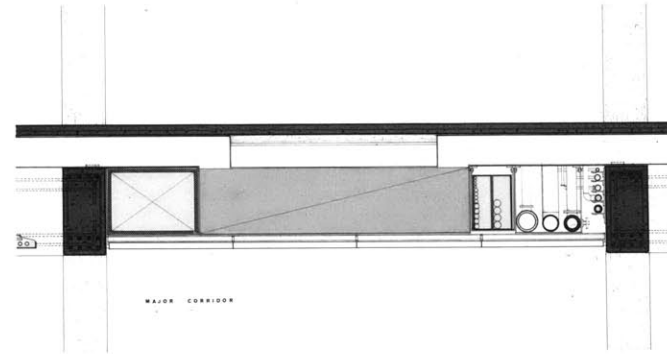
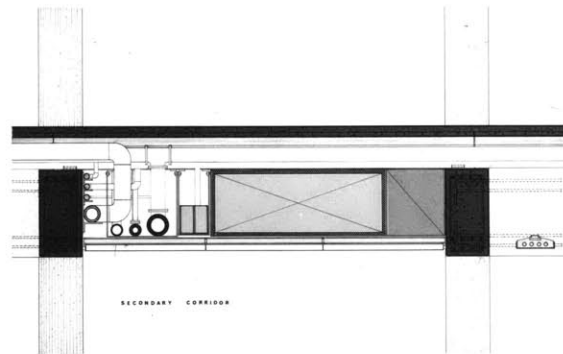
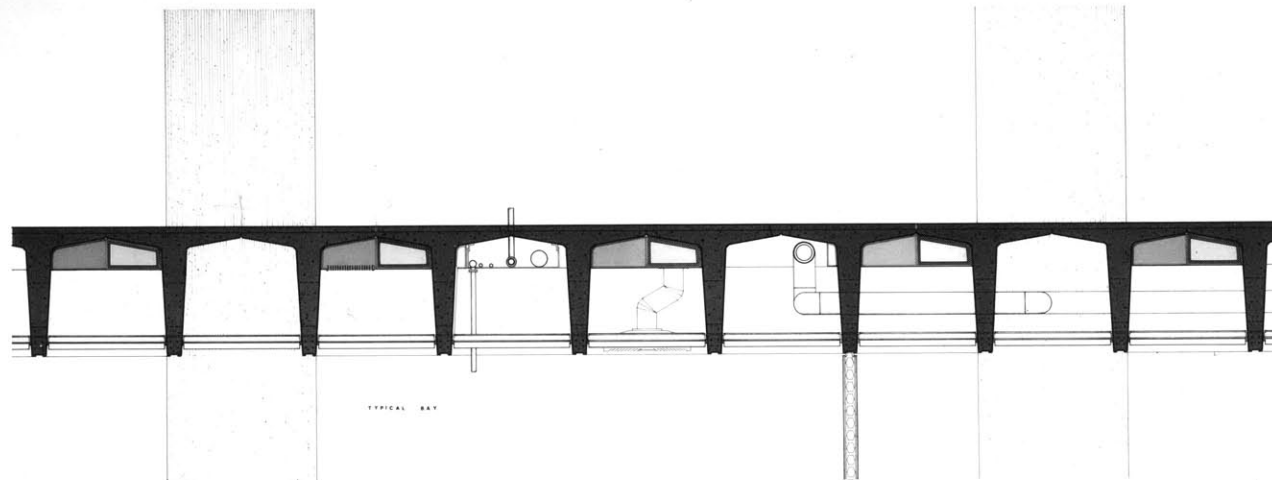
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PERIMETER WALL DETAILS  
1 2 3 4 5 6 7



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MISCELLANEOUS DETAILS  
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